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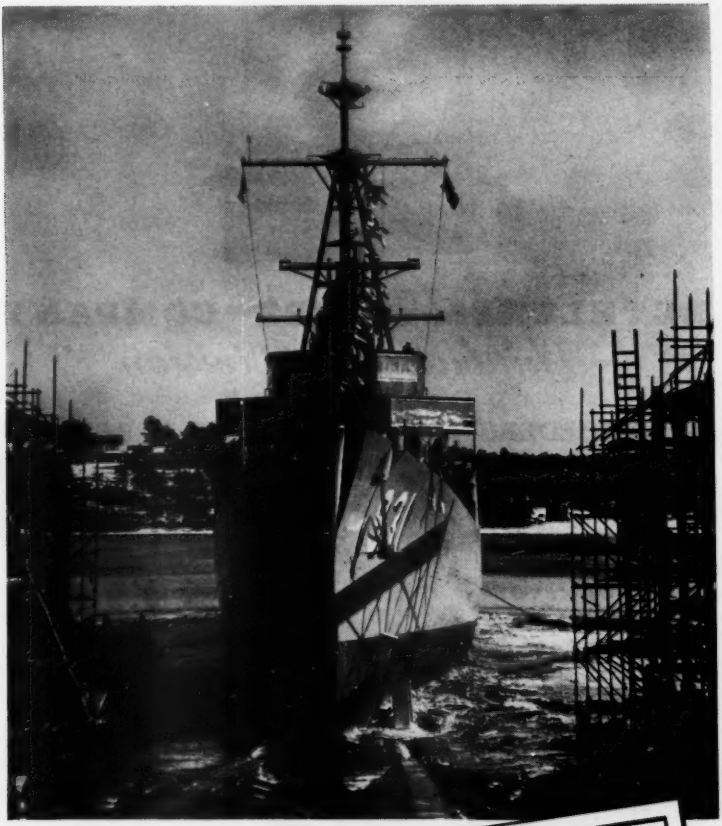

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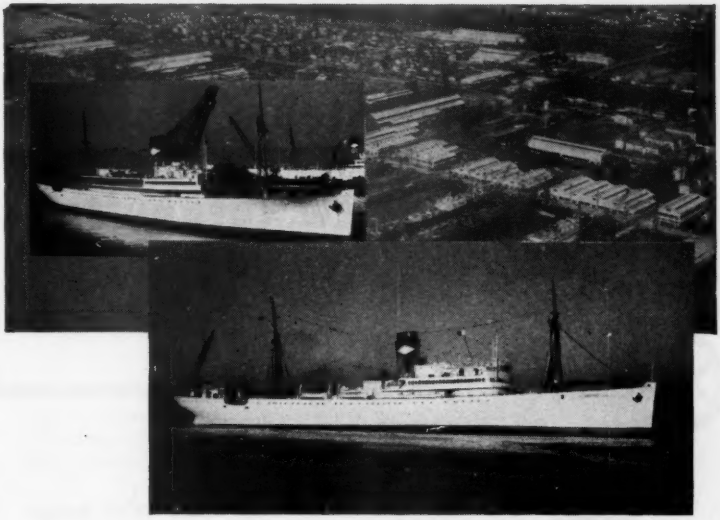

Above . . . the Veragua ties up for alterations. At right . . . a sister ship, the Quirigua, after conversion.

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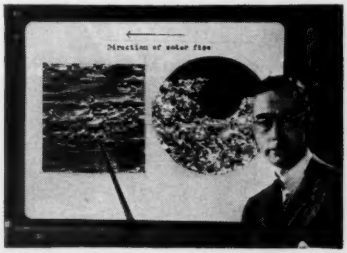

Left, impingement corrosion of Admiralty tube by high velocity sea water with air bubbles. Right, section through part of horseshoe-shaped pit.

of course, our Technical Department stands ready to assist you in the selection of tube alloys from our extensive line. *The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.* 54105A

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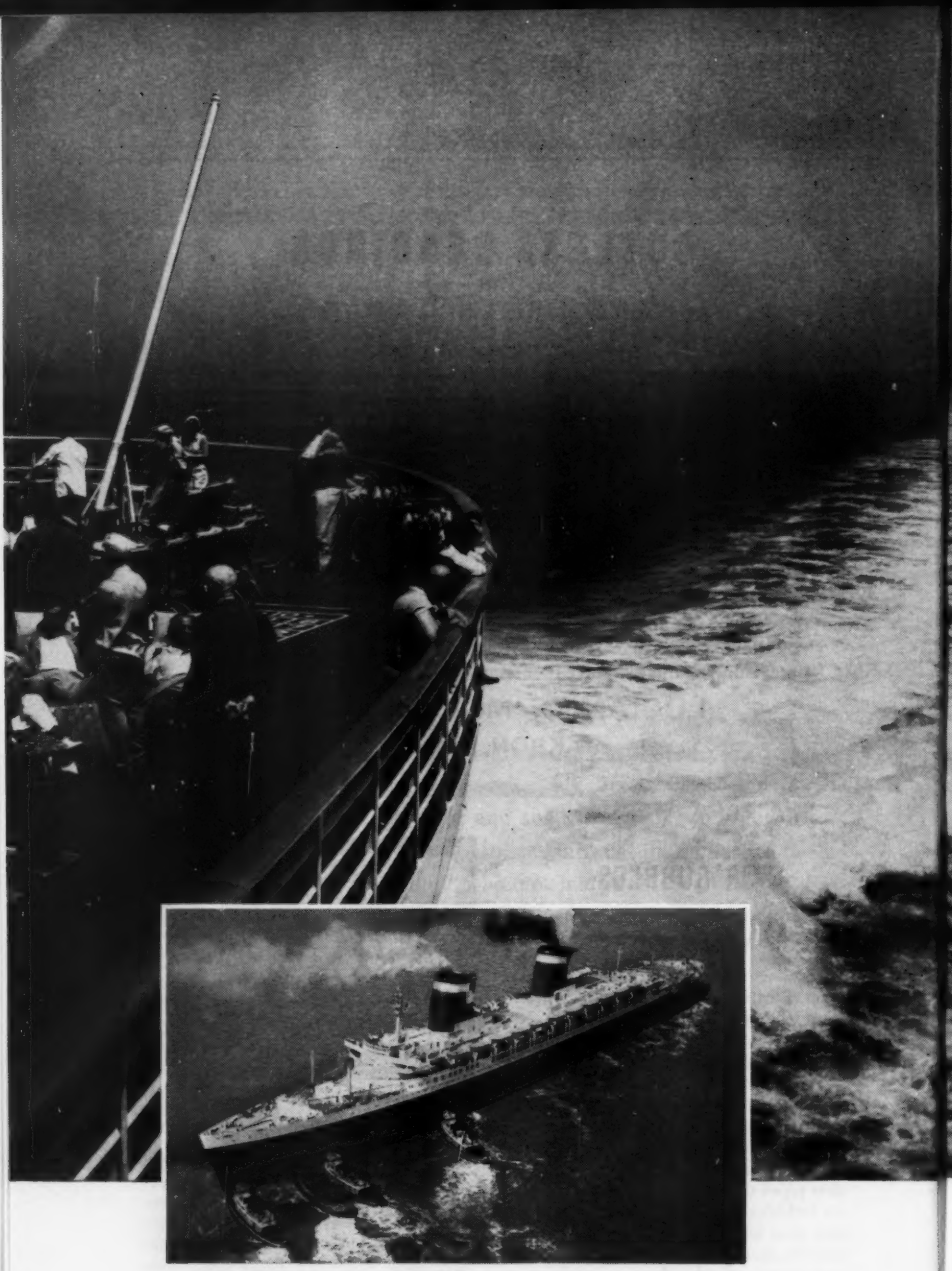

More than a quarter-million miles of water have passed under the stern of the S. S. United States since the vessel's maiden voyage July 3, 1952. While the actual horsepower data cannot be revealed for security reasons, during two successive days on the maiden voyage, she averaged over 36 knots or nearly 42 statute miles per hour.

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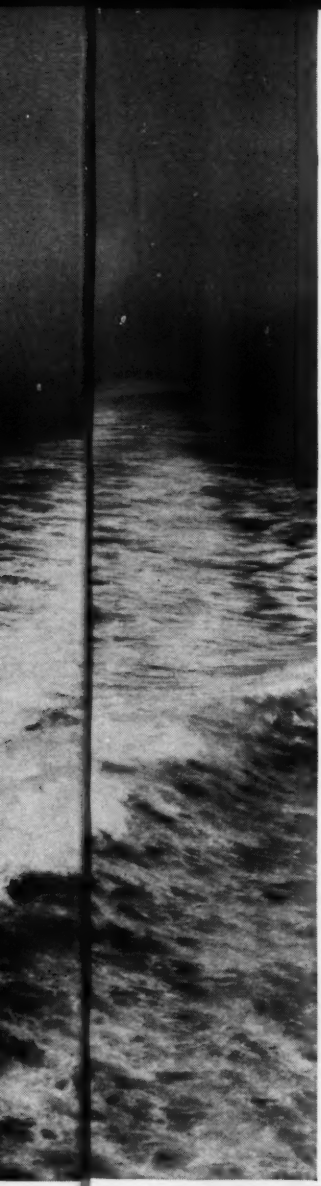

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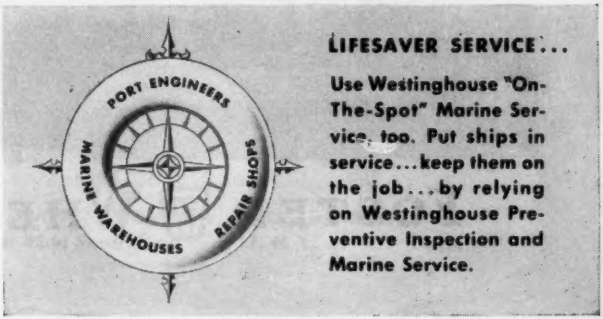

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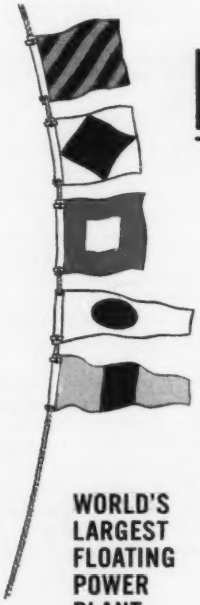

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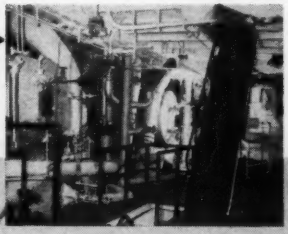
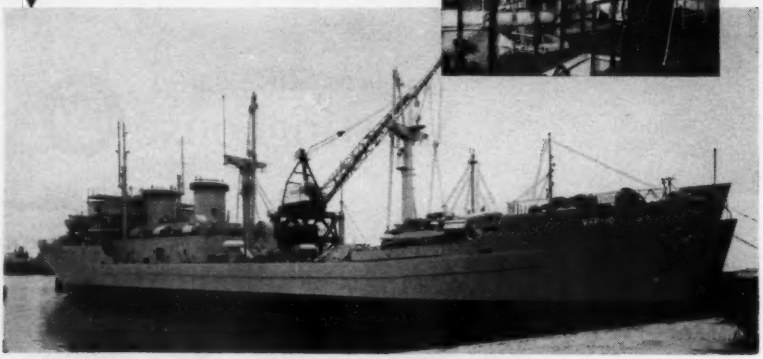


U. S. Navy YFP-10, turbo-electric generating plant, capable of delivering 34,000 kw at 13,000 v. Built for the Bureau of Yards and Docks by the Gibbs Corporation, Jacksonville, Fla. Power plant designed by Reynolds, Smith and Hills, Engineers, Jacksonville, Fla.



FOSTER WHEELER

The "ways & means" committee is back in session

This is probably one of the healthiest scenes that anyone interested in the welfare of the United States could hope to see. It's a symbol, to begin with, of what the recent passage of the 124.6 million dollar Ship Fund Bill means to our national maritime industry.

It's much more than men going back to work; it's a ***movement toward U. S. preparedness and prestige.*** These men, and thousands like them, soon will be engaged in adding to one of America's most vital peacetime agencies and wartime defense arms—the Merchant Marine. And, right now, if anything needs to be added to, it is the United States Merchant Marine. This kind of awareness can help take us from the ***number seven*** position in ship construction in the world to a position that befits our commercial status and results in our readiness for any emergency.

Let what you see above symbolize a continuous situation. Through *your* interest and awareness this scene can be, should be, an occurrence that happens every morning of our future—until we can safely answer the question, "How's the Merchant Marine?," with "Big, strong and ready."

The Babcock & Wilcox Company, which has helped to power so many thousands of American ships, is continuing to work in the tradition of engineering excellence which has made the U. S. A. the world's leader in the design and construction of merchant and naval vessels.

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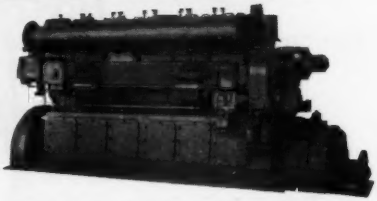

truly advanced engineering, has enabled Cooper-Bessemer Diesels to do a notable job in Navy and Coast Guard vessels from the biggest combat ships to relatively small patrol boats. Yes, you can always count on Cooper-Bessemers for Diesel performance at its finest.

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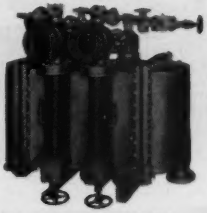

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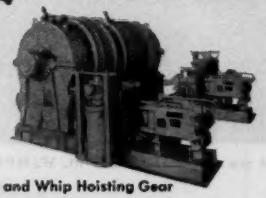
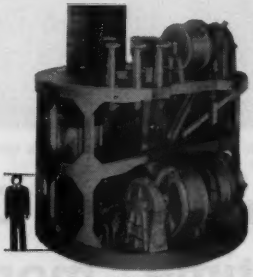


Boat Crane and Whip Hoisting Gear



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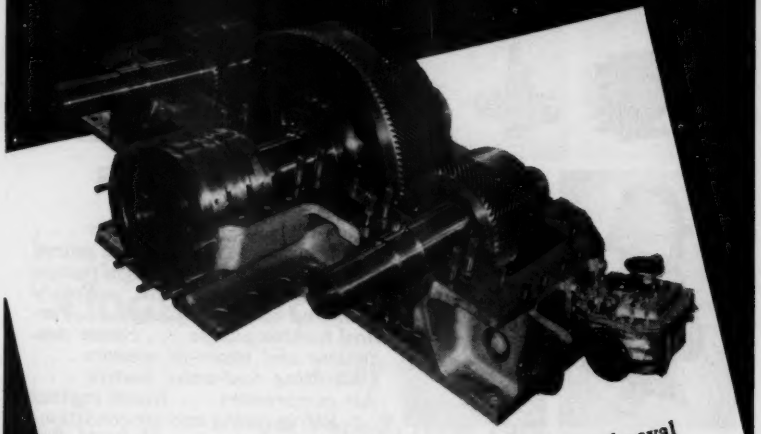

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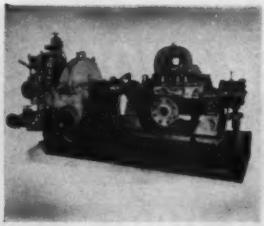
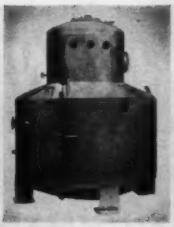
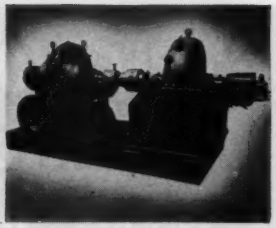

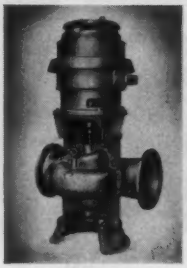
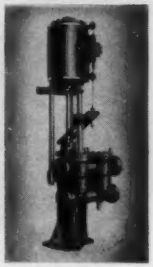
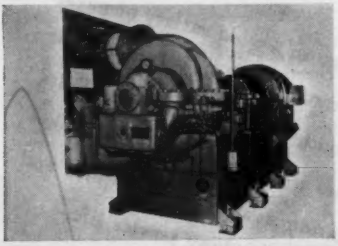

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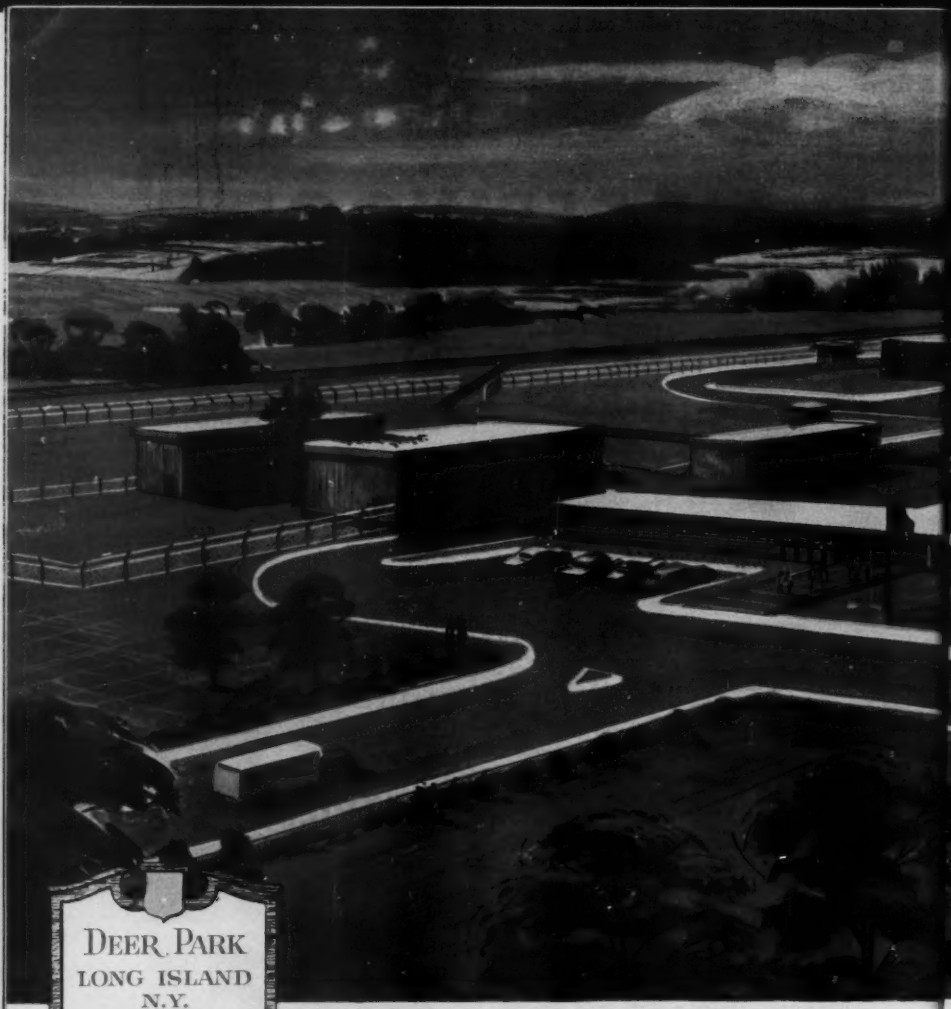

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Important new developments in *power* are programmed for this new Fairchild Engine Division plant and turbine test laboratory now under construction at Deer Park, Long Island.

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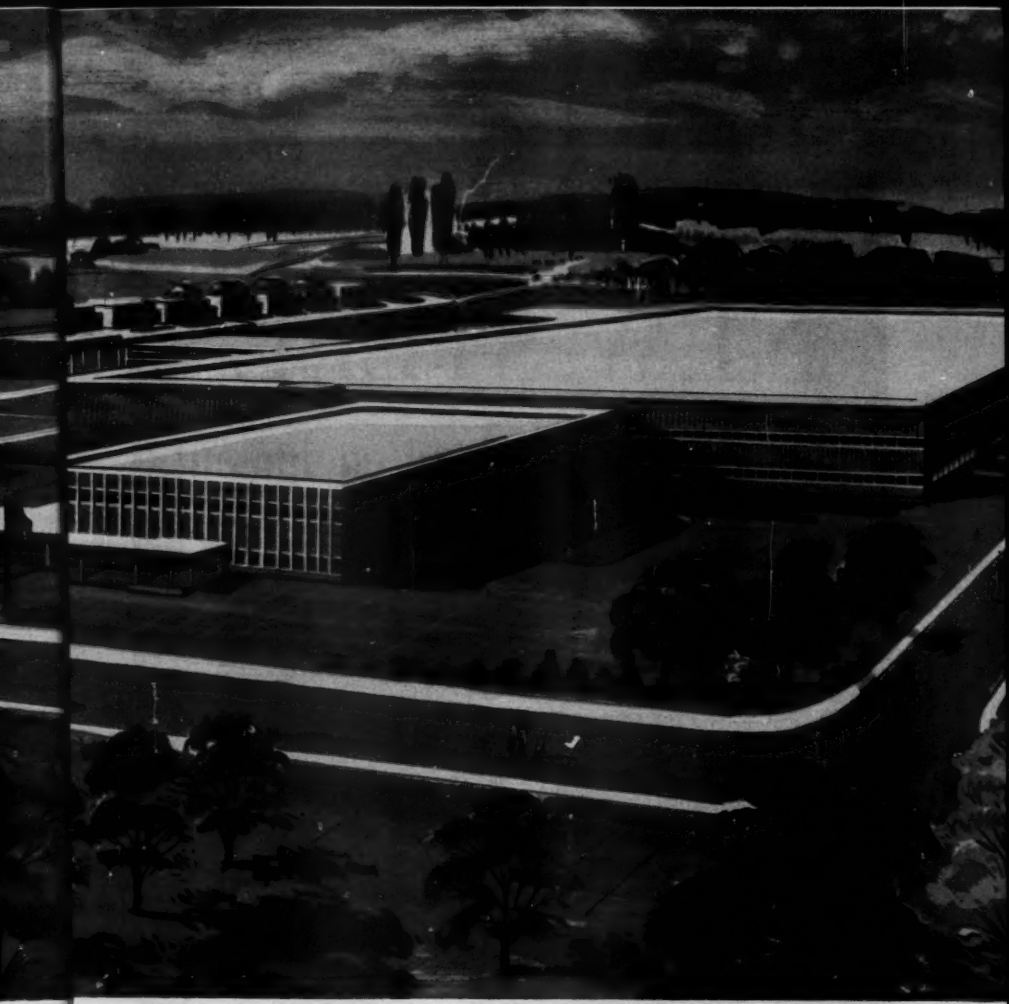

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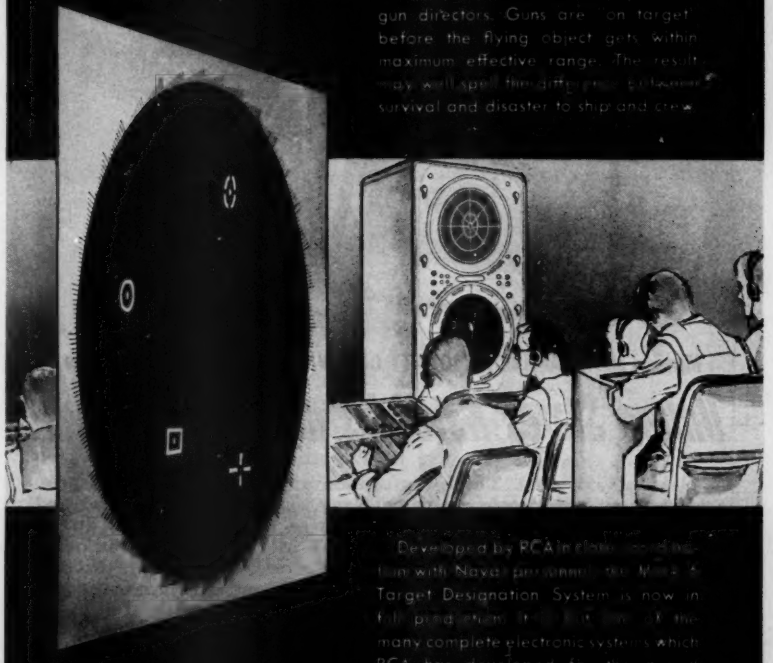

Developed by RCA in close collaboration with Navy personnel, the Mark 1 Target Designation System is now in full production. It is one of the many complete electronic systems which RCA has developed for the armed forces. RCA engineering—from original planning to final production—assures greater efficiency, effectiveness and safety in operation.

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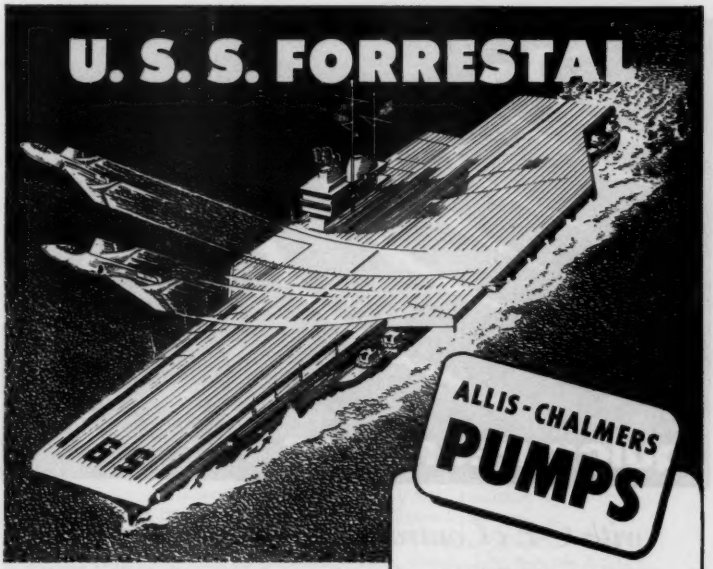

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5	8x6 SKD	Fire
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The C-E Controlled Circulation boiler has an inherent characteristic which makes possible a rapid response to change in load. At sea or in port this is a factor that counts. The propulsion plant with C-E Controlled Circulation boilers is able to respond more quickly to maneuvering bells, with steadier water levels and steadier superheated steam temperatures. In putting a boiler on the line, the circulating pump assures positive circulation which means the pressure parts are heated more evenly, thus keeping metal temperatures more uniform and reducing thermal stresses. The same advantage applies in taking the boiler off the line, making it possible to cool the boiler more quickly. Where quick response is an important factor, check on the advantages of the C-E Controlled Circulation Boiler.

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JOURNAL

OF

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Vol. 67 | MAY, 1955 | No. 2

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SECRETARY'S NOTES

1955 BANQUET

On Friday, 29 April 1955, the Society held its 37th annual banquet. The location, at the Statler Hotel in Washington, was the same as has been used since the banquets were resumed after the war in 1946. The first banquet which was held in 1909 saw 122 dinners served. The next one, in 1911 had an attendance of 182. The latest one, which continued the steady growth of the past required service for about 1850. This is more than we had considered to be the maximum capacity of the Statler. However, means were found for accommodating all who desired to attend.

The retiring president of the Society, Rear Admiral W. D. Leggett, Jr., USN, retired, presided and also acted as toastmaster. He introduced his successor as President Rear Admiral F. R. Furth, USN, Chief of Naval Research.

Rear Admiral A. G. Mumma, USN, Chief of the Bureau of Ships, acting for the Council, presented certificates of Life Membership, for outstanding contributions to the Society and to Naval Engineering to:

Mr. E. C. Magdeburger and
Mr. K. D. Williams.

The principal speaker for the evening was Mr. John Jay Hopkins, President and Chairman of the Board of General Dynamics Corporation. Mr. Hopkins' talk was entitled "The Engineering Challenge of the Atomic Age."

Announcement was made of the unanimous vote of the Council to nominate Mr. Arthur G. Fessenden to Honorary membership. This was in recognition of Mr. Fessenden's loyal and devoted service, now in its 47th year as Administrative Assistant.

The First Banquet

In 1909, to celebrate the coming of age of the Society, a banquet was held for the first time. This affair was described in the Journal as follows:

SOCIETY BANQUET

The Secretary-Treasurer has to announce that the banquet of the Society held at Raucher's, Washington, D.C., on May 17th, was a most successful event and one thoroughly enjoyed by all who attended.

Rear Admiral J. K. Barton, President of the Society, introduced as toastmaster Commander W. Strother Smith, who discharged the duties of that position in a most admirable manner.

The toasts were as follows:

"The President."—Responded to by Senator M. E. Clapp, member of the Naval Committee.

"The Navy."—Responded to by Rear Admiral C. S. Sperry, U.S.N.

"Naval Engineering."—Responded to by Rear Admiral Richard Wainwright, U.S.N.

"The Navy and the People."—Responded to by Representative W. E. Roberts, member of the Naval Committee.

Besides these, there were short speeches delivered by Representative A. F. Dawson, member of the Naval Committee; Assistant Secretary of Navy Beekman Winthrop; Prof. F. R. Hutton, of Columbia University; Hon. L. A. Coolidge, late Assistant Secretary of the Treasury, and Mr. Robert Patchin, of the *New York Herald.*

Mr. John Armour, of *Power and the Engineer,* added much to the entertainment by giving some of his delightful recitations.

The success of this banquet has brought forth from many quarters the hope that the practice of giving a Society banquet each year may be established.

The following is a list of the guests and members who attended:

H. L. Aldrich; General J. B. Aleshire, U. S. Army; Darwin Almy, George Anthony, Edward R. Archer, J. Armour, Lewis Audenreid.

Captain F. H. Bailey, R. O. Bailey; Rear Admiral J. K. Barton, U. S. Navy; Lieutenant H. A. Baldridge, U. S. Navy; Commander F. W. Bartlet, U. S. Navy; Commander F. C. Bieg, U. S. Navy; Lieutenant R. L. Berry, U. S. Navy; Scott Bone, W. A. Bole, G. M. Bond, George K. Bradfield, J. A. Breckons, L. M. Brigham, George Brill; Commander H. V. Butler, U. S. Navy; Hon. J. C. Burrows.

Otto Carmichael; Captain E. H. Campbell, U. S. Navy; Lieutenant Commander L. H. Chandler, U. S. Navy; R. H. Chappell, Hon. M. E.

Clapp, Walter E. Clark; Lieutenant Commander H. I. Cone, U. S. Navy; L. A. Coolidge, C. A. Cotterill.

Arthur P. Davis, O. K. Davis, Hon. A. F. Dawson, Charles Delanoy, John Derby; Lieutenant H. C. Dinger, U. S. Navy; T. Dunlap; Commander C. W. Dyson, U. S. Navy; Commander T. C. Fenton, U. S. Navy; W. D. Forbes, Koerting Fischer.

Lieutenant J. B. Gilmer, U. S. Navy; Hon. A. W. Gregg, H. B. Gregory; Commander R. S. Griffin, U. S. Navy.

Lieutenant Norman Hall, U. S. Revenue-Cutter Service; F. H. Halsey, General Harries, G. G. Hill, Hon. C. D. Hilles; Rear Admiral R. C. Hollyday, U. S. Navy; Lieutenant Commander U. T. Holmes, U. S. Navy; J. C. Hoyt, W. D. Hoxie; Captain John Hubbard, U. S. Navy; C. W. Hunt, Prof. F. R. Hutton.

Rear Admiral Richard Inch, U. S. Navy.

E. N. Janson, J. E. Jenks, Arthur Johnson.

L. H. Kenney; Lieutenant H. Kotzschmar, U. S. Revenue-Cutter Service.

Hon Herman de Lagercrantz, Swedish Minister; John W. Lieb, John Lloyd, Charles Longstreth, Luther D. Lovekin, F. R. Lowe; Rear Admiral John Lowe, U. S. Navy; Lieutenant Commander J. M. Luby, U. S. Navy.

Engineer-in-Chief C. A. McAllister, U. S. Revenue-Cutter Service; Hon. C. McHarg; Rear Admiral T. C. McLean, U. S. Navy; Rear Admiral N. E. Mason, U. S. Navy; H. A. Magoun, Prof. Lionel Marks, E. D. Meir, A. B. L. Mesney, Fred J. Miller; Lieutenant Commander J. P. Morton, U. S. Navy; Richard Morton.

Commander H. P. Norton, U. S. Navy; L. B. Nutting.

J. C. O'Laughlin; Captain Hugo Osterhouse, U. S. Navy; C. B. Overbaugh.

Captain W. M. Parks, U. S. Navy; Robert Patchin, N. B. Payne, John Platt; Paymaster C. T. Peoples, U. S. Navy; Pitman Pulsifer.

A. H. Raynal; Lieutenant Commander M. E. Reed, U. S. Navy; Captain I. S. K. Reeves, U. S. Navy; Captain J. E. Reinburg, U. S. Revenue-Cutter Service; Hon. J. B. Reynolds, C. R. Richards, Calvin W. Rice, F. H. Rittenour, Hon. E. W. Roberts, F. E. Rodgers; Lieutenant C. S. Root, U. S. Revenue-Cutter Service; Captain W. G. Ross, U. S. Revenue-Cutter Service; T. F. Royland.

J. A. Seymour, Arthur Scrivener, W. E. Schoenborn; Commander W. S. Smith, U. S. Navy; James M. Smith; Pay Director J. N. Speel, U. S. Navy; Rear Admiral C. S. Sperry, U. S. Navy; F. Starck; Major Stanley, U. S. Army; J. A. Stewart; Lieutenant George Sweet, U. S. Navy.

Lieutenant Elisha Theall.

Hon. George Uhler.

Rear Admiral Richard Wainwright, U. S. Navy; Ernest Walker; Chief Engineer J. Q. Walton, U. S. Revenue-Cutter Service; Jesop

Banquet. American Society of Naval Engineers. May 7, 1909.

Westesson; Commander W. W. White, U. S. Navy; Hon. William H. Wiley, Hon. Beekman Winthrop, I. H. Woolson, Oresco Woolson; Captain Walter F. Worthington, U. S. Navy.

It is thought that this banquet will have a large influence in making the Society more widely known, enlarging the number of its members and friends, and assisting the Society in carrying out its aim in the promulgation and improvement of engineering knowledge throughout the Service.

The following comment appeared in the Army and Navy Register:

"A notable event in many respects, aside from the commensality of the occasion, was the banquet with which the members of the American Society of Naval Engineers celebrated the twenty-first anniversary of the organization of that body. The dinner occurred in Washington on Friday of last week, and was attended by representatives of Congress from both the House and Senate, by naval officers of distinguished service and by members of the American Society of Mechanical Engineers, lately in convention in Washington.

"The post-prandial addresses were out of the ordinary in the fact that the speakers had something to say and stopped when it was said. It is worth recording that the sentiment of the public expressions on that occasion was appreciative of naval engineering as a factor which contributes so directly and vitally to the success of naval operations. Such influential officers of the Service as Rear Admirals Sperry and Wainwright found it possible to give enthusiastic testimony of the efficiency of the engineering branch of the American ships of war, and especially the battleships of the circumnavigating cruise. The importance of naval engineering requires no exploitation, but it was well to have an opportunity to manifest service and congressional realization of what naval engineering has been, is and should be."

The accompanying photograph is reproduced through the courtesy of the *Army and Navy Register* and Photographers Harris & Ewing, of Washington, D.C.

H. C. DINGER
Secretary-Treasurer

FUTURE BANQUETS

Future banquets will continue to be held on Friday, normally the last in April, but occasionally on the first in May. The next affair is scheduled for 27 April 1956. There has been improvement in the facilities which are available in Washington for parties of the size and nature of the Society's. The President has continued the 1955 banquet committe to serve for 1956. Its first mission is to decide on the location of the 1956 banquet. Members will be informed as soon as possible after decision is reached.

COUNCIL MEETING

A meeting of the Council was held in Washington, D.C., on 13 April 1955. We have already mentioned the action which was taken in regard to awards and to the 1956 banquet. Other business transacted is covered below.

THE PRESIDENCY

Incident to his retirement and moving from Washington, Admiral Leggett tendered his resignation. This was accepted, effective as of 1 May 1955. The Council then appointed Rear Admiral Frederick R. Furth, U.S.N., Chief of Naval Research as President to succeed Admiral Leggett for the remainder of 1955.

It will be recalled that Admiral Furth was appointed to succeed Admiral Sylvester in 1954. Since Admiral Sylvester remained in Washington his resignation did not become effective. Admiral Furth did not serve in 1954. His photograph appeared on page 266 of the issue of the JOURNAL for May 1954.

COUNCIL MEMBERSHIP

Admiral Furth's appointment as President will create a vacancy in the Council on 1 May. Captain J. M. Farrin, U. S. Navy, who is on duty in the Bureau of Ships of the Navy Department, has been appointed, by the Council to complete Admiral Furth's term which expires on 31 December 1955.

Captain Webster announced his expected transfer from the *Washington*, probably in June 1955. To provide for the vacancy which would then be created, the Council appointed Commander W. D. Brinckloe, U.S.N. to the Council vacancy effective on the date of Captain Webster's departure from the area. This term expires on 31 December 1956. Commander Brinckloe is also on duty in the Bureau of Ships.

THE BY-LAWS

Lack of currency in the by-laws was brought to the Council's attention and was discussed. There are two things which have not kept pace with re- and re-reorganizations of the Department of Defense. In both cases the Council decided that the desired change could be taken care of as a matter of interpretation.

One of the matters is the provision for ex-officio Honorary members. As the by-laws now read, they fit the organization of some time ago when there were but four civilian secretaries in the Department of the Navy. There are now seven. Since the titles have been changed, it is not easy to determine just who are or are not Honorary members. The interpretation which has been approved by the Council is of this nature:

"That provision in paragraph 19 of the By-laws which now reads: 'The Secretary of the Navy, the Under Secretary of the Navy, the Assistant Secretary of the Navy, the Assistant Secretary of the Navy for Air . . . shall be Honorary Members'

shall be changed to:

'The Secretary of the Navy, the Under Secretary of the Navy and all Assistant Secretaries of the Navy who are appointed by the President by and with the consent of the Senate . . . shall be Honorary Members.' "

The other matter stems from the establishment of the Department of Air and the separation from the U. S. Army of the Officers who entered the U. S. Air Force. Army officers have been eligible for Associate Membership without sponsorship. The change will provide similarly for officers of the U. S. Air Force.

The Council also directed the Secretary-Treasurer to prepare a change in the by-laws, to be submitted to the membership, providing honorary membership for the Secretary, Deputy Secretary and Assistant Secretaries of Defense.

AWARDS COMMITTEE

The following report of the Awards Committee was presented and approved without change by the Council:

"The committee considered its precept which reads: "For the present, the function of this committee will be to consider any recommendations for Honorary Membership which may be received and to make recommendations to the Council on these nominations."

In view of the precept, no final action was taken on establishing criteria for considering any recommendations which were received. It was decided to treat each recommendation on its merits.

Previous to the formation of the Awards Committee, the Council had acted favorably on the recommendation of Rear Admiral W. D. Leggett, Jr., USN, in regard to Mr. E. C. Magdeburger. The committee unanimously agreed to report to the Council that it concurred in the action of the Council that a Certificate of Life Membership be presented to Mr. Magdeburger on the occasion of the annual banquet of the Society on 29 April, 1955, with the following citation:

> "In view of his considerable contributions in the diesel engine field, his leadership and vigor in the adoption and use of diesel engines by the U. S. Navy, his inspiration and guidance to the many naval engineers and young officers who worked with him, and his outstanding performance as a good citizen, the Council of the American Society of Naval Engineers takes great pleasure in designating Edward C. Magdeburger a Life Member of the Society."

and that his name be printed on the ballot for the 1956 election of officers with recommendation for election as an Honorary Member.

The committee considered the recommendation of a member, Captain W. R. Millis, USN, Ret., in regard to Mr. K. D. Williams and unanimously recommends to the Council that a certificate of Life Membership be presented to Mr. Williams on the occasion of the annual banquet on 29 April, 1955, with the following citation:

> "In view of his outstanding contributions in the field of metallurgy, for the great resourcefulness, initiative and ability which he exercised in bringing about fulfillment of many programs of highest importance to the Navy, for his counsel to many Naval Engineers and young officers with whom he has worked and for his good citizenship, the Council of the American Society of

Naval Engineers takes great pleasure in designating Karl Dayton Williams, a life member of the Society"
and that his name be printed on the ballot for the 1956 election of officers, with recommendation for election as an Honorary Member."

JUNIOR MEMBERSHIP COMMITTEE

The following report of the Committee on Junior Membership was submitted and approved by the Council:

"19 April 1955

From: Chairman and Members on Committee for Junior Membership
To: President, American Society of Naval Engineers, Inc.
Subj.: Committee on Junior Membership; report of
Encl.: (1) List of Schools accredited by the ECFD that are not on the NROTC List

STATEMENT OF PROBLEM:

To offer a two year's trial membership at reduced rates as a Student Associate member in the Society to :

1. All Seniors who are members of the following:
   U. S. Naval Academy.
   U. S. Military Academy.
   U. S. Coast Guard Academy.
   Webb Institute of Naval Architecture, or
2. All Seniors who are Engineering Students of the following:
   U. S. Merchant Marine Academy.
   California State Maritime Academy.
   Maine State Maritime Academy.
   New York State Maritime Academy.
   Massachusetts Maritime Academy.
   Fifty-two Universities and Colleges where NROTC Units are established, or
3. All Seniors who are Engineering Students of any college or university accredited by the Engineers Council for Professional Development.

PLAN:

a. Each fall the Secretary will write to the Dean of Engineering or appropriate official at each of the schools where the Junior Membership is authorized outlining the plan and requesting that it be called to the attention of those who may be interested. Application blanks will be included with this letter.

b. To those students who take advantage of the offer which requires payment of one year's dues in advance, eight issues would be sent. When the seventh issue is mailed, a letter (under separate cover) would be sent to the student member explaining that this was the next to the last issue under the (2) two year junior membership plan and enclosing an application blank for enrollment, as a regular member. Upon mailing of the eight (8) copies of the JOURNAL, the Student Membership would automatically terminate.

CONCLUSION:

The Committee is in full agreement that the plan is sound and that if implemented should stimulate a greater interest among younger engineers in the field of Naval Engineering.

Therefore the committee recommends that the Society approve the following for Junior membership and that action be taken to implement the plan.

1. All Seniors who are members of the following:
   a. U. S. Naval Academy.
   b. U. S. Military Academy.
   c. U. S. Coast Guard Academy.
   d. Webb Institute, or
2. All Seniors who are Engineering students of the following:
   a. U. S. Merchant Marine Academy.
   b. California State Maritime Academy.
   c. Maine State Maritime Academy.
   d. New York State Maritime Academy.
   e. Massachusetts Maritime Academy, or
   f. Fifty-two (52) Universities and Collegs where NROTC Units are established.
3. All Seniors who are Engineering students of any College or University accredited by the Engineers council foı Professional Development.

C. H. CAMPBELL
Commander, USNR
Chairman"

List of Schools Accredited by the Engineer's Council for Professional Development that are not on the NROTC List

Akron, University of
(Akron, Ohio)

Alabama, University of
(University, Alabama)

Alaska, University of
(College, Alaska)

Arizona, University of
(Tucson, Arizona)

Arkansas, University of
(Fayetteville, Arkansas)

Bradley University
(Peoria, Illinois)

Brooklyn, Polytechnic Institute of
(Brooklyn, New York)

Bucknell University
(Lewisburg, Pennsylvania)

California Institute of Technology
(Pasadena, California)

Carnegie Institute of Technology
(Pittsburgh, Pennsylvania)

Case Institute of Technology
(Cleveland, Ohio)

Catholic University of America
(Washington, D.C.)

Cincinnati, University of
(Cincinnati, Ohio)

Citadel, The
(Charleston, S.C.)

Clarkson College of Technology
(Potsdam, New York)

Clemson Agricultural College
(Clemson, S.C.)

Colorado A&M College
(Fort Collins, Colorado)

Colorado School of Mines
(Golden, Colorado)

Connecticut, University of
(Storrs, Connecticut)

Cooper Union School of Engineering
(New York, N.Y.)

Dayton, University of
(Dayton, Ohio)

Delaware, University of
(Newark, Delaware)

Denver, University of
(Denver, Colorado)

Detroit, University of
(Detroit, Michigan)

Drexel Institute of Technology
(Philadelphia, Pa.)

Fenn College
(Cleveland, Ohio)

Florida, University of
(Gainesville, Florida)

George Washington University
(Washington, D.C.)

Hawaii, University of
(Honolulu, Hawaii)

Houston, University of
(Houston, Texas)

Howard University
(Washington, D.C.)

Iowa, State University of
(Iowa City, Iowa)

Johns Hopkins University
(Baltimore, Maryland)

Kansas State College
(Manhattan, Kansas)

Kentucky, University of
(Lexington, Kentucky)

Lafayette College
(Easton, Pennsylvania)

Lehigh University
(Bethlehem, Pennsylvania)

Louisiana Polytechnic Institute
(Ruston, Louisiana)

Louisiana State University
(University, Louisiana)

Lowell Technological Institute of Massachusetts (Formerly Lowell Textile Institute)
(Lowell, Massachusetts)

Maine, University of
(Orono, Maine)

Manhattan College
(New York, N.Y.)

Maryland, University of
(College Park, Md.)

Massachusetts Institute of Technology
(Cambridge, Mass.)

Massachusetts, University of
(Amherst, Massachusetts)

Michigan College of Mining and Technology
(Houghton, Michigan)

Michigan State College
(East Lansing, Michigan)

Mississippi State College)
(State College, Mississippi)

Missouri School of Mines and Metallurgy
(Rolla, Missouri)

Montana School of Mines
(Butte, Montana)

Montana State College
(Bozeman, Montana)

Nevada, University of
(Reno, Nevada)

New Hampshire, University of
(Durham, New Hampshire)

New Mexico College of A. and M. Arts
(State College, N. M.)

New York, City College of
(New York, N.Y.)

New York State College of Ceramics (at Alfred University)
(Alfred, New York)

New York University
(New York, N.Y.)

Newark College of Engineering
(Newark, New Jersey)

North Carolina State College
(Raleigh, N.C.)

North Dakota Agricultural College
(Fargo, North Dakota)

North Dakota, University of
(Grand Forks, N.D.)

Northwestern University
(Evanston, Illinois)

Norwich University
(Northfield, Vermont)

Ohio University
(Athens, Ohio)

Oklahoma A&M College
(Stillwater, Oklahoma)

Pittsburgh, University of
(Pittsburgh, Pa.)

Pratt Institute
(Brooklyn, New York)

Rhode Island, University of
(Kingston, Rhode Island)

Rose Polytechnic Institute
(Terre Haute, Indiana)

Rutgers University
(New Brunswick, N.J.)

Saint Louis University
(St. Louis, Missouri)

Santa Clara, University of
(Santa Clara, California)

South Dakota State College
(Brookings, S.D.)

South Dakota School of Mines
(Rapid City, S.D.)

Southern Methodist University
(Dallas, Texas)

Stevens Institute of Technology
(Hoboken, New Jersey)

Swarthmore, College
(Swarthmore, Pa.)

Syracuse University
(Syracuse, New York)

Tennessee, University of
(Knoxville, Tennessee)

Texas, A&M College of
(College Station, Texas)

Texas College of Arts and Industries
(Kingsville, Texas)

Texas Technological College
(Lubbock, Texas)

Texas Western College
(El Paso, Texas)

Toledo University
(Toledo, Ohio)

Tulsa, University of
(Tulsa, Oklahoma)

Union College
(Schenectady, New York)

United States Naval Postgraduate School
(Monterery, California)

Utah State Agricultural College
(Logan, Utah)

Vermont, University of
(Burlington, Vermont)

Virginia Military Institute
(Lexington, Virginia)

Virginia Polytechnic Institute
(Blacksburg, Virginia)

Washington, State College of
(Pullman, Washington)

Washington University
(St. Louis, Missouri)

Wayne University
(Detroit, Michigan)

West Virginia University
(Morgantown, W. Va.)

Wichita, Municipal University of
(Wichita, Kansas)

Worcester Polytechnic Institute
(Worcester, Massachusetts)

Wyoming, University of
(Laramie, Wyoming)

The Secretary-Treasurer reported that the interim action directed by the Council had been taken. An application form had been prepared and copies of it sent to the appropriate official at each of the schools concerned. This action limited eligibility to the members of the graduating class of 1955. The result to date is that ten applications for Junior Membership have been received. It is doubtful that sufficient time has elapsed to test the acceptance of the new form of membership.

JOINT ENGINEERING MEETING IN WASHINGTON, D.C.

The last issue of the JOURNAL carried a notice of this meeting. It. the first of its kind, is considered, by its sponsors, to have been successful. The principal address by Dr. John Jacob Theobald, President of Queens College, Flushing, N.Y. is reproduced in full, starting on page 279 of this issue.

THE ENGINEER

The following excerpt from *Engineering* issue date 21 January 1955 should be of interest to all members of the engineering professions.

"Definitions of the "professional engineer" and the 'engineering technician" are published in the January issue of *The Chartered Mechanical Engineer* (the journal of the Institution of Mechanical Engineers). They are reproduced below as a matter of interest to all who come within one or other of these categories.

The definition of a professional engineer lacks the directness and altruism of Tredgold's famous words.* The purpose of the engineer's work was the core of Tredgold's definition, but it is by-passed in the new definition. In its place we have a careful and elaborate formula based on the word "engineering." All that is needed now is a definition of engineering.

But the new definition is superior to Tredgold's in one important respect—it has been agreed by all the principal engineering institutions of the British Commonwealth, the United States and Western Europe, except the Institution of Engineers, Australia. So far as the British Commonwealth institutions are concerned, agreement to use these definitions was reached at their Conference held in London last summer. (A report on this conference is published in *The Chartered Mechanical Engineer*.) It is, presumably, correct to infer that a corporate member of one of the three British chartered institutions is necessarily a "professional engineer," and equally that an "engineering technician" cannot be a corporate member of any of these institutions. But this point is not specifically made in the report of the Conference.

PROFESSIONAL ENGINEER

A professional engineer is competent by virtue of his fundamental education and training to apply the scientific method and outlook to the analysis and solution of engineering problems. He is able to assume personal responsibility for the development and application of engineering science and knowledge, notably in research, designing, construction, manufacture, superintending, managing and in the education of the engineer. His work is predominantly intellectual and varied, and not of a routine mental or physical character. It

*"The art of directing the great sources of power in Nature for the use and convenience of man."

requires the exercise of original thought and judgment and the ability to supervise the technical and administrative work of others.

His education will have been such as to make him capable of closely and continuously following progress in his branch of engineering science by consulting newly-published work on a world-wide basis, assimilating such information and applying it independently. He is thus placed in a position to make contributions to the development of engineering science or its applications.

His education and training will have been such that he will have acquired a broad and general appreciation of the engineering sciences as well as a thorough insight into the special features of his own branch. In due time he will be able to give authoritative technical advice, and to assume responsibility for the direction of important tasks in his branch.

ENGINEERING TECHNICIAN

An engineering technician is one who can apply in a responsible manner proven techniques which are commonly understood by those who are expert in a branch of engineering or those techniques specially prescribed by professional engineers.

Under general professional engineering direction, or following established engineering techniques, he is capable of carrying out duties which may be found among the list of examples set out below.

In carrying out many of these duties, competent supervision of the work of skilled craftsmen will be necessary. The techniques employed demand acquired experience and knowledge of a particular branch of engineering, combined with the ability to work out the details of a task in the light of well-established practice.

An engineering technician requires an education and training sufficient to enable him to understand the reasons for and purposes of the operations for which he is responsible.

The following duties are typical of those carried out by engineering technicians:

Working on design and development of engineering plant and structures; erecting and commissioning of engineering equipment and structures; engineering drawing; estimating, inspecting and testing engineering construction and equipment; use of surveying instruments; operating, maintaining and repairing engineering machinery, plant and engineering services and locating defects therein; activities conected with research and development, testing of materials and components; and sales engineering, servicing equipment and advising consumers.

ERRATA

In the February issue, page 8, we called attention to the fact that Figure 1 of "Aerodynamic Torque Loads on Rotating Radar Re-

flectors" by Dr. Melvin Mark on page 953 of the November 1954 issue of the JOURNAL, had been printed upside down.

Another regretable erratum, in this article, which came to our attention too late to include in the February issue is:

On page 955, right hand column, fourth line from the top should read:

"... Two dimensionless parameters were used, $T_{max}/\frac{1}{2}\rho V^2D^2H$) and (ND/V), and from ... etc." There should not be a period or blank space after "used," the words following it being part of the same sentence and thought.

WHAT DOES MEMBERSHIP IN THE AMERICAN SOCIETY OF NAVAL ENGINEERS MEAN?

The American Society of Naval Engineers has, from its inception, limited membership to individuals. Admission to membership is based on personal qualifications. Membership is a means of recognizing individuals who have attained acknowledged proficiency of some degree in one of the many branches of Naval Engineering.

The individualness of the Membership appears to be lost sight of in some cases. The principal cause of this seems to be that membership dues are treated as business expense. The dues of some members are paid by the employer who sends company checks directly to the Society for this purpose. This practice is entirely satisfactory to the Society, but we feel that it is incumbent on the individual to accept the responsibilities of membership by insuring that the following rules are followed:

a. Each check should carry the names of the member for whose acount, IN THE SOCIETY, the check is drawn; or should be accompanied with the Society's bill for dues; or should have a forwarding letter giving this information.

b. When a member severs connection with a company which has been paying his dues, he must realize that his dues will still continue as a matter of his own responsibility unless he submits a personal resignation.

c. Employers should be advised that there is no Company Membership and that membership is not transferrable. Any member *whose account* is paid up to date may resign. Any qualified person may apply for membership in the normal way. A "transfer" can be accomplished only by carrying out these two transactions.

Neglect of these rules have been responsible for making a great deal of annoying correspondence necessary.

Another area in which a small number of members, apparently try to take advantage of their fellow members, shows up each year before the annual banquet. It seems that some, in an anxious effort to beat the dead-line for banquet applications, submit lists of names to make up their party with little or no assurance that the guests listed will accept an invitation. Later, wholesale changes in the makeup of the party are submitted, sometimes in several parts.

There is one rule which covers this but it is very difficult to administer fairly. That rule states that no application which is not correct in all detail will be accepted and that the date on which the application will be recorded will be the one when the last discrepancy is cleared up. Applying this rule broadly would handicap those members who submit a correct application but who, later, through uncontrollable circumstances find it necessary to delete names or to make substitutions. The seating committe makes every effort to treat each case fairly and only where the patency of the attempt to mislead is conclusive, is the applicant deprived of the priority to which his earliest submittal entitled him.

We honestly see no reason why all hands should not consider the rules of fair play which the officers, Council and Committees of the Society believe to be essential for the honored continuation of the Society. It is hoped that nothing more than this mention will be necessary.

MEMBERSHIP LIST FEBRUARY, 1955

We have recently printed and distributed a Membership List of the Society as of February 1955. For our limited staff this was no small task. The cost was in the order of $3,000.00. Hence, it is apparent that we cannot publish these lists very frequently.

The information which was used for the published membership list was the latest in our files. An attempt had been made in 1954 to bring these files up-to-date by sending out a questionnaire to all members. Returns on these questionnaires were somewhat better than might be expected from a public opinion poll but far less complete than desired.

A number of errors and omissions in the membership list have been brought to our attention. We cannot disclaim responsibility for all of them but the major cause is that members do not advise us specifically of a change of title, change of employment or even of a change of address. There are some who seem to feel that we can pick up this kind of information from general knowledge of naval promotions or transfer orders; or from the mimeographed sheets which some companies distribute broadly when there is a change in the status of their more important employes; or from the daily newspapers or technical press. This is an impossibility and we feel that the partial results which might be obtained if we attempted this would result in endless confusion.

We feel that each member alone must be fully responsible for the information which we have on file about himself. The information which we would like to have about each member is:

Full name.
Rank, if a military person.
Title of his office of employment.
Company affiliation, if any.
Mailing address, which is to be used for the JOURNAL and for all Society correspondence.

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CONTRIBUTIONS OF ENGINEERS AND ARCHITECTS TO AMERICAN PRODUCTIVITY

DR. JOHN JACOB THEOBALD

This talk was given by Dr. Theobald in Washington, D.C. on 23 February 1955. The occasion was a meeting sponsored by the D.C. Council of Engineering and Architectural Societies to honor the engineering, architectural and scientific societies of the National Capital Area.

Dr. Theobald is a native of New York, N.Y. He is an educator of renown, an author of distinction, and an engineer by training. He has been a special lecturer at the School of Engineering, Columbia University, since 1943, and was a special lecturer at that University's School of Architecture from 1944 to 1949, as well as Dean of Administration of City College, 1946 to 1949. He has been President of Queens College since 1949.

As an author, Dr. Theobald has had published, "An Economic Analysis of Highway Administration in the State of New York," "Hydraulics for Firemen," "Civil Engineering," and "Engineering for Society."

As an engineer, he is a registered professional engineer in the State of New York, and a member of the American Society of Civil Engineers, the American Road Builders Association, and the Society for the Promotion of Engineering Education. As a member of the community, Dr. Theobald has served as an enthusiastic civic leader, director of charitable organizations, and a public administration consultant.

In a very true sense the practice of architecture and engineering must have begun with the earliest appearance of man, for basically they are concerned with harnessing the natural law and directing it toward human service.

The first stone, rolled back and forth before the entrance to a cave; the twisted vine that helped to climb a tree; the log rolled across the brook; all these were elementary beginnings of now distinguished professions.

I wonder sometimes, were they less significant contributions than we are making today?

The earliest domestic buildings of which we have a record are probably the lake dwellings which lie at the bottim of some of the Swiss lakes. Similar structures have been found elsewhere in both the eastern and western hemispheres.

They are rudely constructed timber huts built on piles and sometimes occur in such numbers as to form fair sized villages. Their location afforded security against the threat of predatory

animals and the sudden attack of enemies. It brought the inhabitants about as close to their place of business (their fishing and hunting grounds) as they could get without risking the malaria and fever of the swampy shore. Even their sanitation, though crude, was about as satisfactory as that day had to offer. I have no way of knowing whether they thought of all of this, and I'm inclined to believe it was more probably evidence of the importance of artistry in engineering than conscious city planning but the evidence of design in accordance with human needs is certainly there.

As civilization developed, so did man's skill at harnessing the forces of nature. The glory that was Egypt could never have existed but for the irrigation works which transformed a narrow strip of arid land 900 miles long into the fertile valley of the Nile.

The valley of the Tigris is another case in point. Who would expect a major culture to develop on an alluvial plain subjected to periodic flooding as the result of torrential rains? And yet, that plain is studded for 220 miles with mesa like platforms built of sun-dried brick with stone and brick facing an extensive system of arched drainage culverts. Some of these mounds are a mile in diameter and 200 feet high. On top of them rest the ruins of ancient Babylonia.

History is replete with evidences of civilizations dependent upon architectural and engineering works. Could ancient Greece have existed without its harbors and its temples? What of a Roman Empire without the intricate network of roads that bound the little Iberian villages to Rome? What of its cities shorn of the aqueducts, the drainage, the great buildings, the paved streets, the bridges, the public baths or even the public circuses?

It might almost be argued that the so called dark ages were delineated by the cessation of architectural and engineering enterprises, for with the decline of the western Roman Empire, the great Roman public works were allowed to fall into decay and conditions comparable to those of ancient Rome did not reappear again until the advent in 1681 of Riquet's Canal du Midi, followed by the French bridge and road system of the Corps des Ponts et Chaussees, the British Canal Work of Brindley, the roads of Telford and McAdam and the harbor construction of Smeaton and Rennie.

One may debate the precedence of the chicken or the egg but the close correlation is inescapable.

The Renaissance of European culture took place, of course, over a considerable period and many things contributed. The use of guns and gunpowder hastened the overthrow of the Feudal System; the introduction of the mariner's compass made possible the exploration of new continents. The acceptance of the Copernican system of astronomy completely changed man's concept of the Universe; the development of the scientific method, and the increased spread of the world's knowledge to the average man through improved means of communication, all these and many more were necessary to the change.

But from the standpoint of the architect and the engineer in his work today the two most important things to come out of the period from 1500 to 1800 were, the development of science and the scientific method, and the marked change in man's attitudes toward life.

The first of these hardly needs comment in this gathering. It begins with men like Copernicus, Galileo, Newton, Harvey, and van Leeuvenhock and ends for the moment with Urey and Fermi and Meitner and Hahn. The second is more elusive; it has crept upon us so slowly that we are inclined to

take it for granted and assume that it has always been with us. It is the disposition to give more attention to the world as the scene of human endeavor, human aspirations and human emotions. It represents a renewed consciousness on the part of man of his own humanity and places upon us in our professional status a recognized responsibility for the welfare of our fellow man to a degree unequaled in any earlier society. In our present day these two elements have become so closely entwined that it becomes increasingly difficult to separate the world of people from the world of things.

The problem I think becomes clearest when we examine the factors underlying the growth of our modern cities.

There have been three periods of intense urbanization. The era of preeminence of the Roman Empire; the 14th and 15th centuries, and our present machine age.

The first two of these were periods during which trade, defense, and cultural centers developed. Typical of these were Athens, Sparta, Troy, Rome, Constantinople, Naples, Venice, Paris, Milan, Cairo, Budapest and the like. They were located primarily, along the Mediterranean because of the greater ease and safety of sea travel, or at the dominant nodes of natural regions. The trade was largely in rare foods such as spices, hand made articles, and objects of arts. Production centers as we know them today did not exist. The growth of cities during both these eras was materially influenced by the prevalence of slavery. This is particularly significant because it meant that a relatively few slave owners could materially affect both the activities and the size of the entire community.

In 1500, the approximate end of the second period of intense urbanism, the seven great cities of the world in order of population were Constantinople, Paris, Naples, Venice, Milan, Lisbon and Rome.

As late as the beginning of the 19th Century Europe was only 3% urban and with the possible exception of the Orient, where no data was available, there were only 21 cities over 100,000 population in the entire world.

The third era was of course sparked by the growth of industry and the development of the machine. The newly found importance of coal, steam and electric power, and steel caused new communities to spring up along the path of economic flow from coal and iron mines to market.

Villages sprang up at the site of the mines and began to dot any geologic area in which deposits of sufficient magnitude and quality occurred to make the digging worth-while. These are but the start of a chain reaction.

In any society of free enterprise and unrestricted migration, the question of where the ore would be refined, where the pig would be converted to steel, where the forms were rolled or shaped or machined, and where the final product was to be assembled, all these depended upon the cost of bringing coal and steel together, the cost of labor and transportation, the cost of marketing and the like. Under these circumstances, for each region, large or small there were certain locations whose natural economic advantages in one or more of these respects set them apart as the points at which each of the several steps from raw materials to market would take place and at each of these points a city grew.

How large or how small depended of course upon the hinterland and the market but the association of such communities and their industrial function is so marked that the names of many of them and their products have

become almost synonymous. Let's try a few:

> Detroit—Autos; Akron—Rubber; Grand Rapids—Furniture; Tampa– Cigars; Gary, Pittsburgh, Youngstown, Chattanooga, Birmingham—Steel; Elgin & Waterbury—Clocks and Watches; Troy —Shirts and Collars; Lawrence and Fall River—Textiles; Endicott and Brockton– Shoes; Corning— – Glass; Danbury– Hats; etc.

The chain reaction however does not end here. As might be expected the development of production centers, especially under a free enterprise system, created broader purchasing powers and vast new markets. Many of these arose in new locations. For example:

The Columbia River in the days before the intense settlement of the west was a highway for trappers. Grubstaked on the coast they would move up the river in the early fall, set their traps, collect their pelts and carry them back down by canoe or flatboat until the widening waters of Puget Sound made such craft impractical as a further means of transportation. Foremost among those fostering such trips were the Astor fur interests. Their west coast business thrived and grew. Ultimately it was decided to establish a center at which the work of collecting and storing the furs for loading onto ocean going vessels could be accomplished. The site selected was on the Sound some ten miles in from the ocean and perhaps sixty miles northwest of where the river begins to widen. They may well have been influenced by the proximity of the Fort which Lewis and Clark built there in 1805.

Appropriately they called their new community Astoria and placed the wealth and strength of one of the nation's leading business fortunes behind its building.

There was only one drawback and I don't suppose that seemed too serious then. The craft which could negotiate the upper waters of the Columbia with its white water and portages could not safely navigate the more open stretches of the Sound.

The trouble probably started when some enterprising pioneer, grown weary of wintering in the hinterlands, built a cabin at the junction of the Columbia and the Willamette. It must have been a welcome spot to stop at for the tired trapper and his loaded boat. Especially when a nice warm fire was burning and the wind was blowing the froth off the tops of the waves on the open water ahead.

Be that as it may, the cabin became a favorite unloading spot. New sheds had to be added for the storage of pelts. Men had to be hired for the unloading and loading; men brought wives; families brought children; people employed in the fur business required others to supply food, recreation, schooling– a city had begun. Subsequently the develpment of the railroad further augmented the same location. Today, spread upstream a little to meet subsequent influences, it is Portland the principal city of Oregon while Astoria boasts a population of 12,331. No reasonable amount of subsidy could have overcome the natural economic advantages of Portland's location.

Portland and the industrial centers are but an example. In the world wide sense even vaster changes have taken place. None of the seven great cities of 1500 are now in the ranks of the leaders. In their stead we find New York, London, Shanghai, Tokyo, Moscow, Chicago, and Buenos Aires in that order.

Not only did the development of modern industry result in new cities at new locations, the same engineering skill and ingenuity that created indus-

try made possible larger agglomerations of people than ever before.

The concentration of large populations in one place presents major problems of food, health and safety, communications and the like. New York City would burn to the ground in 72 hours without its modern water supply. How long could it maintain its present size and character without steam, electricity, refrigeration, telephones, gas, plumbing, subways? What would its recreational and emergency communications problems be without radio or television? What if the truck, the steamship, the railroad and the airplane stopped coming to the city's gates? What if the machinery that ended subsistence farming and made it possible for one man to provide the food for many disappeared?

Truly our modern metropolis is in itself a gigantic engineering project. It could not exist but for the exercise of practically every engineering and architectural skill which today's society has at its command.

It is not surprising then to find that not only the cities but the world itself has changed, 96 or 97% rural in 1800 it is now almost 60% urban. The 21 cities over 100,000 at the beginning of the 19th century had increased to over 500 by 1930 with 31 cities in the "million" class.

Furthermore this rise has continued. The threat of the technicrats in the twenties and early thirties that we were on the verge of technological bankruptcy has not materialized and in its stead scientific progress and resultant urbanism has been markedly greater than before. Today there are 20 cities with over 2,000,000 residents; 53 with more than 1,000,000; and 114 with over half a million.

For the architect and the engineer these past 200 years have been a "heyday." The rapid expansion of industry, the discovery of new scientific principles, the creation of new materials, the development of new markets coupled with intense speculation, have created an almost unlimited demand for our professional services.

During such an era we could hardly fail. Almost anything we turned our hand to—a building, a new electronic device, a servile mechanism, a pair of skates, a new frying pan, a plastic packaging for cheese, all were almost bound to succeed. Whether or not they represented the best that could be done was of relatively little significance. In fact in many areas consumers have come to expect a "new and better" product at annual intervals. Frequently the one thing which has tended to maintain standards has been the innate drive of the engineer for perfection.

In this mad competitive orgy there is one area which we have almost completely forgotten. We have, as I previously pointed out done an excellent job of the design, production and improvement of each of the various engineering elements which go into making our modern society possible. But we have done little looking at the project as a whole. Maybe we have been too busy or haven't seen its implications; maybe the benefits or disadvantages are so widely spread that no one man or company can afford to pay the cost; but that fact remains that the responsibility for the overall look at this social structure which we have built—even its overall design and improvement—we have left to the social scientist. Isn't this tantamount to dropping problems which we create into some one else's lap for solution? Would this in any other situation be considered good engineering practice? This may not have been too serious in the past but we are rapidly moving into an era where mere congestion may destroy present economic advantage of loca-

tion, point where the increased cost of social and welfare problems may well offset the value of the business dollar.

When our modern industrial and trade cities first developed, the natural advantages which each city enjoyed were directly reflected in better living for the people it served—In greater National wealth!

As our city's primary functions have developed toward the maximum of its capacity however, men have competed for a chance at the profits. Real estate prices have risen and even the business organizations themselves have taken on anticipatory values which are sold and traded in. These speculative costs have naturally been added to the sales price of the articles produced until finally much if not all of the natural advantage of location is being lost to the buyer.

The situation has been further aggravated by the intensity of traffic congestion. This may well result in excessive local transportation and delivery charges, and increased cost of and demand for the social and welfare services which always accompany the large city operation.

Clearly when these factors become large enough both to eat up the natural economic advantages of location and to overcome the innate resistance to moving, business enterprises leave the city and they leave not only at a loss to the city but at a loss to society and to themselves. Long before this point is reached many of those who can afford it will have moved to the suburbs in the search of "Lebensraum." Under this situation the collective ability of the municipal taxpayer to pay drops off far more rapidly than does the cost of government and again in the overall sense no one is the gainer.

Some of our American cities have already reached this point. But a great modern city is not as easily disbanded as it was begun. Future generations will still be paying for facilities and services which have long since become obsolete.

Plato in his Republic pointed out that an intelligent and socialized community should continue to grow only as long as it can remain a unit and keep up its common institutions. Beyond that point growth must cease or the community will disintegrate. Have we not, we who have built these modern cities, long since permitted them to go beyond this critical point?

It seems to me, as I look ahead that we architects and engineers must be concerned relatively less in the future with how to build and more with whether or not to build; that increasingly we shall find that the critical loads are human loads rather than pounds; that the stresses and strains which govern our designs will be social ones and that we shall be more and more put to it to make a dwindling supply of raw materials more adequately meet the increased demands of advancing social consciousness and a growing population.

This rather than atomic energy and nuclear fission is our challenge of tomorrow. We will have no difficulty mastering the technical facts of the new science and converting them into productivity. This we have been trained to do and do well. For the human problems which we create—those are another matter. Too long we have left their solution to others when in truth they can be adequately solved only with the help of careful and understanding design prior to their creation.

We engineers and architects are an ancient profession. We carry a great responsibility for the creation of our modern world. But unless we adopt the relatively new sciences of man and his society as part of the tools of our trade we may find that we are building a Tower of Babel.

DOES YOUR ENGINEERING ORGANIZATION PASS THE WORD EFFECTIVELY?

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THE AUTHOR

was born September 6, 1911, at Somerville, Mass. He graduated from the U.S. Naval Academy in June 1934, from the Submarine School in June 1937, and from the Post Graduate Course in Design Engineering, USNA, 1943. In 1946 he took the Advanced Management Course at the Harvard Graduate School of Business Administration. He has served in all departments on cruisers, as a Naval Aviation Gunnery Observer and as Commanding Officer of submarines. He was designated for Engineering Duty only in 1946 and since has served as Deputy Head Electrical Branch in the Bureau of Ships, as Design Superintendent at the Portsmouth Naval Shipyard, and is now Head of the Electrical Branch in the Bureau of Ships.

INTRODUCTION

Organized communication began when the first tribe sat in a circle and allowed only one man to talk at a time. As civilization became more complex so did its methods of communication, until today we find almost infinite variation in the methods used to impart thoughts. In an engineering organization the abilty to communicate is of paramount importance, since the organization in itself performs no direct manufacturing action and functions primarily to create ideas and tell or show others how to carry them out. On the surface it would seem that an engineering organization dealing with generally precise things would have little difficulty with communications compared to, say, a political organization dealing with human emotions or desires. A little examination will disclose, however, that in fact many of the difficulties encountered in an engineering organization are not concerned with the evolution of ideas at all, but rather are the result of trying to communicate these ideas by the wrong method, in the wrong manner, or to the wrong persons. This article examines some of the accepted methods of communicating ideas in an engineering organization, both written and verbal, to see where mistakes are commonly made, and to suggest what can be done by executives to improve communications in the organization.

Effective communication in an engineering organization is a most

difficult and complex process; it is also an absolute necessity if the many specialties are to be welded together into an integrated whole whose product meets requirements in the most economical manner. A modern design organization proceeds by a process of evolution to its goal and many different types of people and personalities are necessary to achieve its end. If one accepts this premise, the need for diverse and different methods of communication seems self-evident. In spite of this, lack of communication by using the wrong media is commonplace. As an example, I am sure that we have all seen engineers poring over an electrical plan in conference, the electrical engineer explaining why his system needs closer governor control from the mechanical engineer's turbine. If pinned down, however, the mechanical engineer may not understand the problem at all because he does not understand the symbols used to denote electrical components. The reverse may be equally true, and merely shows that although plans are an accepted medium of conversation for imparting exact information between engineers, they may not accomplish this in design conferences between specialists in different fields. Working vertically instead of across organizational lines, management can thoroughly confuse an engineer by painting such a broad picture of an objective in its directives that the engineer's detailed investigations are wasted. Communications are important because they are the method by which diverse ideas are welded into a whole; they are difficult because of the many levels and cross levels found in an engineering organization.

Compounding the problem are the usual problems of communications found in any organization such as semantics, informal versus formal chains, changes as communications go through different levels, and the normal problems of achieving understanding in a large group. We will leave these to the more general fields of management and will concentrate on the problems of an engineering organization upon which these are superimposed.

MANAGEMENT CONTROL TYPES

1. *The "Map" technique in Communications.*

Communication in an organization is very aptly described by the "map," an analogy first described by Professor Fritz Rothlisberger of the Harvard Graduate School of Business Administration. Our discussions in the various areas can very readily be fitted into this framework. Let us imagine that we are about to take a hunting trip from New York to a remote spot in the New England States and have been told of the square mile area in which we are to camp and hunt. Examination of the first three columns in Figure 1 will show us that at least three kinds of maps are necessary to plan the trip and get us there. On arrival, the last map will get us around the local area where we are to hunt. Instinctively we would use the surveyor's, or a small local map, to get compass directions if lost; the New England States map to get to our general locality from a distance; and the others as we traveled closer to our objective. None of them would give the climate, the people living in our hunting area, or our methods of hunting; nor could we use one for the other.

Now we will transfer this series of directions or "maps" into communications in an engineering organization and see how quickly we can get confused if we use the wrong map. Col-

umn 4 shows roughly where the types of communication by directive fit into the organization. The absence of any one, the interchange of one for another, or the use of one type to explain another is bound to cause confusion—and it does! There are undoubtedly omissions in the figure, and the relative vertical place of some items is open to argument; but the general flow serves, I believe, to illustrate the point. Yet we often see General Specifications cluttered up with detailed admonitions, and manufacturing plans with notes or views which should be on system schematics or in instruction books.

When one communicates with the larger scale "map" in mind, he often finds that he is not getting his ideas across because his readers or listeners have their minds focused on a detail "map." The last column gives the level of abstraction used in the horizontal column and shows how words become more specific as we proceed from general objectives to specific design.

Giving or Writing Directives

Avoid mixing Policy with Action and obtain correct levels of abstraction

Map Analogy	Territory	Hunting Purpose	Engineering Direction Map	Engineering Organization Purpose	Level of Abstraction Type Word
New England States	Hunting Territory	Decide what to do	Policy or general instruction. Contract Plan. Artist's conception of product. Market Studies.	Guidance	"Completely" "Truth"
Road map of Maine	Directions to area by automobile	How to get there from a distance	Plan schedule. Hours of work. Arrangement plans. Engineering standards. Overall contract specifications. First cost estimates.	General field of endeavor	Very High "Go West young man"
County map	Local area for hunting, mountains, rivers, trails	What to do when you arrive	Project task. Directive to unit. Assembly drawing. Detailed contract specifications. Models, mock-ups. Cost and weight targets. Schematics, system plans. Engineering sketches.	Specific job.	High "Hydraulics" "Electrical"
Area Sketch (Surveyor's map)	Exact area, meeting places, camp site, etc.	Use on the spot for local hunting	Plan directive. Direction to draftsman. Detail drawing.	Achieve a specific result in a definite time.	Concrete "You" "Tomorrow" "Twenty" "500 psi"

Figure 1

2. *General Non-Verbal Communications.*

The most common non-verbal types of communictaion in an engineering organization are polciy directives, standards, general specifications, plans, detail specifications, calculations, studies of reports, models or mock-ups, pictures, and, for large organizations, conference, and trip reports. We will take some of them up individually and see how they are used. Since engineering organizations vary widely in their size and scope, we shall use a medium size group of about three hundred people, which is either a part of a large division organization or a headquarters engineering group, such

as a technical Bureau of the Navy. We specifically exclude a pure research organization, although many of their problems are similar, and we also exclude written communications dealing with non-engineering matters, such as personnel matters, accounting, and so forth.

3. *Policy Directives.*—The Area Map.

No organization exists in a vacuum —management must give it guidance for those factors which are not within its inherent power to control. Within the engineering organization itself, guidance as to fields of operation must also be given. Policy directives from top management should cover these fields, in order that the organization may base its engineering decisions on an appraisal of outside conditions and general objectives. In order that the flow of ideas may not be unduly restricted, these directives ought to be quite general. They should not state how to accomplish a task, but they must be explicit in explaining the restrictions enforced by outside directives, market, or customer considerations.

The level of abstraction is necessarily high in such directives, and great care must be taken to couch them in terms such that the next tier of the organization can understand them. Too much "policy" soon becomes restrictive and self-contradictory. Too little "policy" results in wasted effort when top management vetoes product ideas after they have been worked out. Many engineering organizations have no expressed "policy" at all. The inevitable result of this is a shifting of the burden to a lower level where interpretations are made on the basis of past practice, a remark from a topside official, or the general philosophy of a unit supervisor. Some of the areas in which policy directives should be issued follow:

AREAS OF POLICY DIRECTIVES

a. The product areas for which the organization is responsible.
b. The organizational framework under which it is to operate.
c. The restrictions imposed upon it from outside, such as higher organization or department rules, laws, price ranges, purchasing restrictions, contract plans, and so forth.
d. Any supporting facilities, subcontracts, and such, which it may use to enhance its own activities.
e. Provision for periodic review by upper and lower levels to see what "areas of ignorance" may have arisen and what changes may be necessary in a fast moving technology.

4. *Internal Operating Directives.*—The State Map.

In this field we come into the grey area of engineering communications. Here we think of such items as engineering standards, overall product performance specifications, integrated plan schedules, and other items which give general directions "across the board" to the specialized engineering groups.

Engineering standards are perhaps the most difficult problems. That they are needed is evidenced by the fact that most companies and organizations have them in some form or another. "U. S. Navy General Specifications for Machinery" is an example of this. Those that do not have them are usually small companies, and even there the project engineers often have the "little black books" which contain a wealth

of past engineering experience. JAN-STD-1 is an example of a Defense Department standard containing drafting rules which unify the drafting methods to be used in Defense Department contracts.

What should be contained in engineering standards? Again referring to our map analogy, we find that we are dealing with direction, not with what we are going to do when we get to the point of detailed engineering work. Engineering standards are the framework of general endeavor within which we should be able to fit the pieces of the products we are designing. In general, they should include:

a. Any components, manufacturing methods, or materials to which the management is committed, such as outside directives, purchase policy, competitive situation, plant facilities, and inventories. Since these channel the engineers' thinking, they should be as few as possible.

b. Any "factors of safety," material characteristics, computational methods, or testing, which the management feels *must* be followed.

c. Drafting, instruction books, and packaging standards establishing general objectives.

From a time sequence point of view overall performance specifications finally emerge as a synthesis of "what we would like to achieve" with "what we can come up with." As such they should never be firm in their initial phases, nor should they fix the individual performance of the parts of the whole.

Overall performance specifications should begin with a consideration of the present fixed requirements and be quite general. It is surprising how former "requirements" change when engineers come up with new ideas which vastly enlarge the capabilities of a product in one direction, while not quite meeting first performance goals in another phase! First conceptions should have ranges of characteristics rather than rigid figures.

After a period of sketches, evaluation, and preliminary design, the overall product specifications set the component and detail specifications for the next step.

5. *Plan Schedules.*—The County Map.

The need for and some of the operations used in plan schedules were discussed in a previous article, "Design Organization," which was published in the August 1952 issue of the JOURNAL of the ASNE. A plan schedule is a limiting form of communication—it describes a series of integrated dates which enable the various designs of a complex product to fit together in orderly sequence. Too often, in the race against time, plan schedules are omitted. They are a direct method of topside communication telling when items must be completed and in what sequence.

INTER-UNIT TYPES OF COMMUNICATIONS

(Local Maps)

1. *Written material at unit level.*

Once below the general fields of endeavor in our "map" analogy, the problems of written communication become more specific and more direct, encounter less different specialties, and thus are less difficult. Unit problems fall under well-known areas of supervision, work assignment methods, and plan preparation, which need not be elaborated here. In general unit level written items are:

a. Project tasks to groups of engineers and draftsmen.

b. Assembly drawings.
c. Schematics and system drawings.
d. Detailed contract specifications.
e. Instruction books.

Individual level written items are:

a. Detail drawings.
b. Instruction book chapters.
c. Computations.
d. Engineering feasibility studies.

2. *Mock-Ups and Models.*

Since engineering organizations deal with the translation of ideas into things, the more physical props that can be used within the organization the better. The money spent on models, mock-ups, pictures, and hand-made samples usually pays off many fold in the end product. No matter how skilled one becomes in reading plans, they are two-dimensional symbols of what an object really is. They are very poor methods of communicating three-dimensional characteristics of objects, like accessibility for maintenance, human engineering considerations of instrumentation, marketability, eye appeal, and arrangement. Because of this two-dimensional aspect, methods other than plans should be considered by management and freely used. Now let us consider them together.

Models and mock-ups are used for many things, but often by trying to combine too many functions in them, their cost is increased inordinately and without commensurate return. The first determination to be made is the problem which the mock-up or model is to solve. A common objective is the achievement of better accessibility or better functional arrangement. For these aims, large or full-scale models or mock-ups can be used. Only limiting dimensions should be used, with outline blocks representing size. Pattern makers, being skilled craftsmen, love to make exact duplicates of diesel engines, for instance, at a very high cost, when a box with major protuberances is all that is needed.

On the other hand, such problems as turbine blading or lighting a compartment do need exact replicas of the object to be built. For high production items a full scale mock-up should be considered as a time-saver in actual manufacture. As an example, after Design was finished with a submarine mock-up, Production used it for actual templets, pipe bends, installation of the first lockers, and placement of fluorescent lighting fixtures.

The use of photographs should not be neglected, particualrly when the problem is to change a previously built arrangement. "One picture is worth ten thousand words!" The cost of models and mock-ups is high, but the cost of correcting errors in the finished product, even if only a prototype, is higher.

3. *Plans.*

Volumes have been written on plans and the science of descriptive geometry is well covered, but there are still many management decisions to be made. Plan preparation has a way of freezing itself in an organization until it becomes stereotyped.

For any new product a fairly high level decision stating what plans are needed for functional or system description, for arrangement purposes, for manufacturing, for installation, and for instruction books, should be made early in design. Just as with models, having one plan cover too many functions looks as though it is economical of engineering time, but often it is not. Modern materials, methods of reproduction, and storage make ink tracings unnecessary in most cases; and clearly penciled drawings will suffice to make distinct reproducibles. The use of "block" or functional drawings is spreading from their orignal application in the electronics field. They should be considered particularly for installation purposes in place of a set

of production drawings, which must be pieced together when different trades are involved. Electro-hydraulic systems furnish an example of this.

A communication channel of low-level, cooperative give-and-take must be set up in the plan process between the design draftsmen, the manufacturing engineers, and the installation personnel. The problems of each should be integrated into a design as it proceeds. It is suprising how poor this chain is in many organizations, but it it not surprising how costly the changes are when the new product passes out of design into tooling, manufacture, and installation. Design and the factory are becoming more and more close, but a large neglected field is still that between the designer and the installation, erection, or assembly personnel. Plans should *not* be relied upon to smooth the way; personal contact between liaison groups is the only feasible answer. The field of plan preparation—how many, what type, and who is to use them—requires a well-thought-out method of communication between the groups of engineering draftsmen, management, and the people who are to translate these plans into articles of value.

4. *Conference and trip reports.*

Large organizations use conference and trip reports to obtain a written record of verbal commitments of their representatives away from the organization. Despite the universal dislike for the effort entailed in their preparation, use of these reports should be a matter of stated policy for all (including topside management!). Guidance should be given as to the desired contents, particularly for the benefit of the more junior members of the organization.

I do not know why, but it seems to be an invariable trait of engineers unaccustomed to writing them, to make a conference or trip report in narrative form. If a narrative must be used, for the sake of an expense claim, or, mistakenly, for the prestige of the writer, for goodness' sake, let's have it as an enclosure! Put the background, purpose, results, and what action is to be taken by whom, on a short concise statement at the beginning. Conference and trip reports are "paperwork," but they provide an indispensable method of communication and prevent the ever-present danger of misinterpretation of words or attitudes afterward. Figure 2, a form used for trip reports in the Bureau of Ships of the Navy Department, is an excellent example of a concise outline.

CONCLUSION

We have shown many methods used in engineering organizations to achieve their goals. The fact that there are so many should cause officers or executives to examine those used (or omitted) in their organizations to keep them effective, streamlined, and properly used.

Each type, from the policy directives of topside management to the functional sketch of an engineer, should be a means to a definite end. Too much emphasis on formal written communication will result in a flood of "paper-work"; too little will result in uncoordinated and duplicated effort. The larger the organization and the more complex or diverse its output, the more demanding the need for unremitting effort to achieve the best form of communication for directives, information, and final design plans, instructions, and specifications.

MEMORANDUM REPORT OF TRAVEL

Subject & file
Code & Serial
Date of Report

Subject(s) and purpose of travel:
1. Person(s) making the trip:

Name(s) Rank/Grade Code:

2. Inclusive dates of trip: from _____ to _____
3. Conference(s) held:
a. Place(s) visited: b. Person(s) conferred with each place:
4. Subject(s) discussed: (topical listing)
5. Brief of Results: (Brief paragraph summarizing information, conclusions, recommendations, or results to provide a digest of necessary information for reviewing officials.)
6. Summary. ((by subject) of information, results, decisions, etc.)
(Make a separate summary for each subject covered)

Enclosures: _____ (Signed)
Typed Signature

Figure 2

The letters reproduced below with permission of the writers are of interest in connection with the preceding article:

DEPARTMENT OF THE NAVY
Bureau of Ships
Washington 25, D. C.

Code 560
1 December 1954

Professor Fritz Rothlisberger
Harvard Graduate School of Business
Administration
Soldiers Field Station
Cambridge, Massachusetts

DEAR FRITZ:

Shades of the Advanced Management Course—your pupil is again about to apply some of your precepts! I'm writing an article for the Naval Engineers Journal on "Communications in Engineering Organizations," a companion piece to one on personnel which they published for me some time ago. In this projected article I illustrate some of the problems involved in group communications by using the "Map" analogue which you taught us. In it I credit you by name with first using it as a tool. My primary reason for writing you is to ask if you object to the map analogue being used in a publication to illustrate specific problems or to your being given credit for its origination.

As a matter of interest I enclose the previous article. Since it is my only copy, would you mind returning it at your convenience? We have many design engineering organizations in the Navy and the two articles are an effort to help them; therefore, they are slanted towards Naval engineering practice. I do feel that the general subject of design engineering, its organization, and its "human relations" problems, has been neglected. Since all other technology depends on them, it might be a fertile field for research (in its non-government aspects) along Harvard lines.

If you are ever in Washington, I'd be delighted to see you and talk over old times at Harvard.

Sincerely yours,

ARTHUR C. SMITH
Captain, USN
(9th AMP)

Enclosure

HARVARD UNIIVERSITY
Graduate School of Business Administration
George F. Baker Foundation

December 7, 1954

Captain Arthur C. Smith, USN
Bureau of Ships
Department of the Navy
Washington 25, D. C.

DEAR ARTHUR:

It was good to hear from you again. Thanks for showing me your previous article. I enjoyed reading it and it seems to me you did a good job of showing the need for effective communication in design engineering organizations.

I don't know just how you plan to use my "map" analogy. But the idea that words (concepts, abstractions, etc.) in relation to the things they refer to can be usefully regarded as being like a map in relation to a territory that is a basic notion in the field of general semantics. Probably Alfred Korzybski in his monumental study *Science and Sanity* started the hubbub. It is used by Hayakawa (see *Language in Thought and Action*) and Wendell Johnson (see *People in Quandries*). But this analogy has come to be so generally accepted that I don't think you will need to give credit for its source unless you go into the matter very intensively.

For Korzybski and the general semanticists the idea that the world of words is to the world of non words as a map is to a territory has tremendous significance; in fact it runs counter to the Aristotelian logic of our common sense world. For example, three propositions follow from this way of thinking.

(1) M/T, i.e. the map is not the territory. Hence the principle of identity of Aristotelian logic, A = A, is "screwy."

(2) M is not all 'T,' i.e. the map is not all of the territory. Therefore any map abstracts certain features from the territory. It always leaves out something. This fact is both the source of its usefulness and the source of many errors. People like to argue from maps, draw implications from maps before checking again with the territory.

(3) M is selfreflexive, i.e. there can be a map of a map of a map etc., i.e. there are levels of abstraction. Hence it is important to realize at what level of abstraction you are. All of this can be diagramatically put in the form of an "abstraction ladder."

	M4—on the road to "ideologies," "principles," "big theories," etc.
	↑
The world of words	M3—first order evaluations, e.g., interpretations.
	↑
	M2—lower order abstractions, e.g., description.
	↑
	M1—labels.
	↑
The world of non-words	Territory

Korzybsky wrote many pages about all this. I am not urging you to read his book but if you are using the analogy of a map to a territory in this way, I think you should acknowledge Korzybski and not me. If, however, you are using the analogy in a more general way, I don't think any acknowledgements are necessary. However, if it makes you feel better and if you want to apply general semantics, you can say "on such and such a date and in such and such a place I heard a guy who in his organization is known as Professor Roethlisberger say, 'Quote,—end quote.' Whether or not this idea is original with him or whether he borrowed it from someone else, I do not know. I also don't know whether or not I am using the idea correctly as he conceived it or as the person

(or persons) from whom he borrowed it conceived it. Nevertheless, I shall apply my understanding of it as best as I can."

I wish you good luck in your next venture of communicating about communication. It's the trick of the century and you had better stay pretty far down on that "abstraction ladder," or should you wish to climb high, at least have some simple operations for coming down pretty fast. You know what happens to a person in climbing down a ladder when the next rung below is not there. Joking aside, I was glad to hear from you and I am glad you are trying to do something about these human relations problems.

Sincerely,
/s/
FRITZ ROETHLISBERGER

FJR:em
Encl 1

THE ELECTRIC LIGHTING PLANT OF THE U.S.S. TRENTON

FIRST U. S. NAVY INSTALLATION.

BY LIEUTENANT-COMMANDER A. M. CHARLTON,
U. S. N., Member.

EDITOR'S NOTE

On page 1390 of the United States Naval Institute Proceedings for December 1954, under the title "The First Light" by Captain Edgar K. Thompson, U. S. Navy, attention was invited to the Navy's first electric generator installation. This first plant which was installed in U.S.S. *Trenton* was described by Lieutenant Commander A. M. Charlton, U.S.N. (presently Rear Admiral U.S.N., Retired) in an article published in the JOURNAL in August 1920. Admiral Charlton's article is reproduced below as a companion-piece to the one by Captain Thompson.

NOTE: The information in this article was compiled from reports from the *Trenton*, contemporary literature and recollections of officers who served on the vessel. The meagerness of Navy reports is indicated by the following extracts from the ship's log on the first day of commission after the electric plant was installed:

September 18, 1883,—

4-8 P. M.—Testing electric lights.

M. L. WOOD.

8 P. M. to Mid. At 10 P. M. stopped dynamo and banked fire in donkey boiler.

W. T. SWINBURNE.

The present day electrification of machinery on naval vessels when practically every moving element receives its motion from an electric motor, and the vessel throughout is illuminated with electric lamps, makes it very difficult to visualize conditions less than forty years ago when there were no electric lights, electric fans or electric auxiliaries. To strip the *New Mexico*, for instance, of her electric plant would be to take away her motive power, her ability to direct, serve and fire her guns, her means of steering and getting up anchor, and the multitudinous systems of interior and exterior communication.

True enough, our vessels forty years ago moved and fired their guns and were lighted, but their arrangements would seem of the crudest sort to-day.

The installation of an incandescent lighting plant on the U. S. S. *Trenton* in 1883 was the first step in the rapid

electrical development which has culminated to-day in our electric drive ships. Before this time there were small interior communication systems such as call bells, thermostats and gun and torpedo-firing systems, but the power involved was negligible and was supplied by wet-cell primary batteries or small hand-driven generators (the Farmer machine on short circuit gave an output of 48 watts, 1/15 H.P.). An engine-driven generator of 5 or 6 horsepower, giving light for an arc lamp, was tried on the *Hartford* in 1877-78 for signalling purposes, but it never got beyond the experimental stage and the successful development of the Very signal system put it in the discard. It has been forgotten even by the people who served on the *Hartford* during its trial.

The fact that the *Trenton* was the first American man-of-war to be fitted with incandescent lamps, and that the installation was made to ascertain the practical efficiency of an electric plant on naval vessels, naturally excited considerable comment, both in and out of the service. One or two passenger vessels and the U. S. Fish Commission Steamer *Albatross* had been fitted with electric plants before the *Trenton* was so equipped, but the latter was a man-of-war, and there was considerable head-shaking. Fear of fires and of failure to withstand the shock of gun-fire, and the usual sea-going opposition to innovations had to be overcome before the work was authorized.

The installation on the *Albatross* was supervised by Passed Assistant Engineer G. W. Baird, U. S. N. (now Rear Admiral, U. S. N., Retired). The contract was made by him and let without competition. There were 154 lamps of 8 candle-power on this vessel.

When it was decided to put an electric plant on the *Trenton*, Lieut.-Comdr. Royal B. Bradford, U. S. N. (late Rear Admiral), who had had much to do with electricity in connection with torpedoes, was put in charge of the work. Passed Assistant Engineer Baird gave him a copy of the contract for the plant on the *Albatross*, and it was Comdr. Bradford's desire to put in a plant on the *Trenton* double the size of that on the *Albatross* as nearly as possible. Early in 1883 seven electric light companies were asked to bid on the installation, but only the Edison Company had the courage or desire to attempt the work as called for by the Bureau of Navigation circular.

The contract was awarded to the Edison Electric Lighting Company at a cost of $5,500. The contract called for one dynamo and engine complete to supply light to the following lamps: 104 16-candle-power lamps, 130 10-candle-power lamps, and 4 32-candle-power lamps, a total of 238 lamps and 3,092 candle power; 238 key sockets for lamps, 6 extra brushes, 1 automatic regulator, and 1 dynamo foundation. All of the necessary conductors, switches, safety devices and appliances were to be of the most approved patterns then used by the Edison Company; and the fixtures for the lights were to be furnished by the Department. This seems a very loosely drawn contract to-day, but at that time there was little previous experience to guide the Navy Department, and, lacking this, the details of the installation were left to the Edison Company, who naturally desired to make the installation as successful as possbile.

The number and type of lamps actually installed differed slightly from the contract specifications, as there were put on board 173 10-candle-power, 70 16-candle-power, and 4 32-candle-power lamps, a total of 247 lamps, and 2,978 candle-power.

The dynamo was of the Edison "L" type, shunt wound with a terminal voltage of 110 and a capacity of 120 ampères, and was rated as a 150 16-

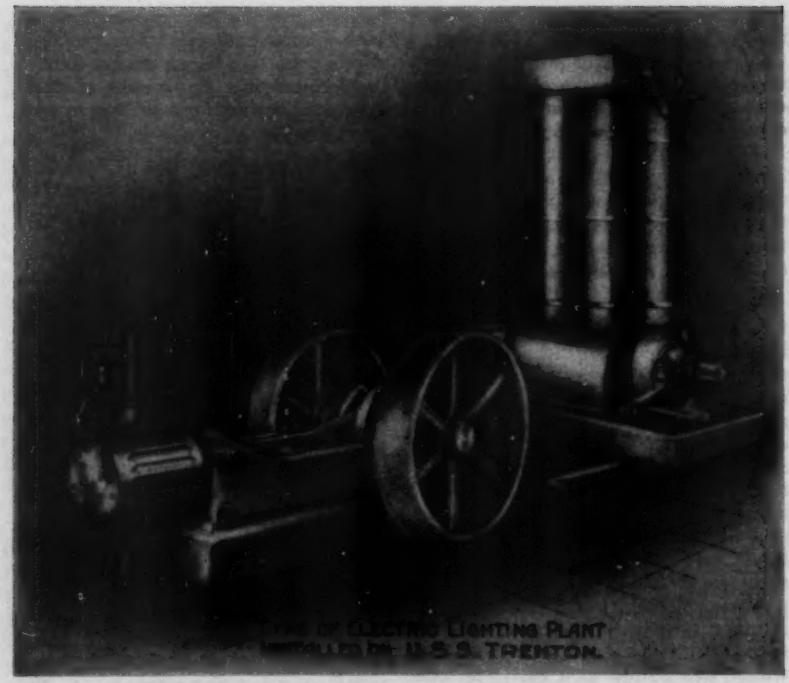
candle-power machine. This would make the rated efficiency of the lamps 5.5 watts per candle-power. At that time (1883) lamps were being made with a rated efficiency of 4.6 watts per candle-power, which would give this 13.2 KW. plant a capacity of almost 2,900 candle-power. As a total of 2,978 candle-power was actually installed, the machine would just about care for the total load in the unlikely case of all lamps burning at the same time.

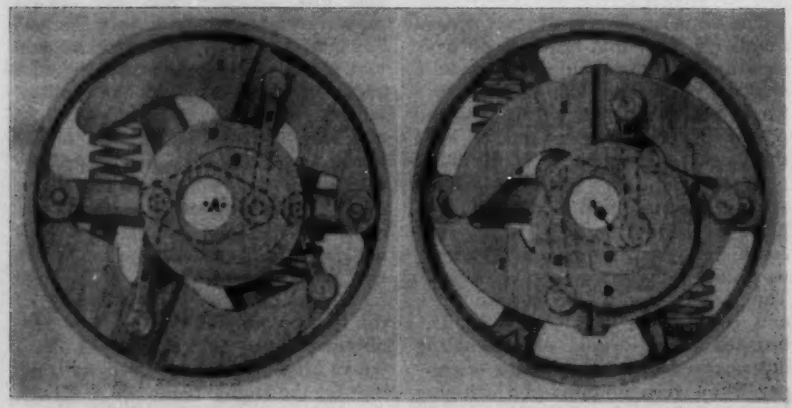
The dynamo was bi-polar, and the four huge field magnets extended to a height of six feet four inches above the deck. These poles were of heavy masses of iron, wound with a great many turns of wire, and the whole covered with cloth for protection. The resistance of the field was in the neighborhood of 40 ohms so that the field current was about 2.75 ampères and the loss in the field .3 KW. The large masses of iron prevented early saturation of the field, and a more powerful machine could be made with a given armature construction and speed. The poles stood on a zinc plate which was bolted to a cast-iron bed plate. On account of the heavy pole pieces used, the weight of the dynamo was 6,000 pounds.

The armature was built up of a large number of very thin disks of soft iron, separated by mica, and strung upon a wooden core. The laminations were firmly bound together by tie bolts and outside of the cylinder so formed were the coils. Of these there was a large number, wound on a modified Hefner-Atteneck system and firmly bound in place by wire bands to prevent the conductors from flying out. The ends were covered with a wrapping of cloth. The commutator was wide and thick and so adapted for long runs. The brushes were formed of alternating layers of wire and thin strips of copper. They were mounted in a swinging frame to allow of proper adjustment. On an extension of the armature shaft was mounted a fourteen-inch pulley with a nine-inch face. The armature was driven by an eight-and-a-half-inch belt from the fly-wheel of the engine at approximately 900 revolutions per minute.

The bed plate of the dynamo was made with slots which fitted over tracks so that the machine could be moved along the deck to compensate for the stretching of the belt. The dynamo was held down by strong bolts passing through the bed plate and the deck, the bolt holes in the bed plate being elongated so that necessary movement of the machine along the tracks would not be interfered with. In addition to the holding down bolts a heavy brass brace was fitted from the top of the dynamo to the bed plate of the engine. The dynamo occupied a floor space 68 inches by 40 inches.

The engine was a horizontal Armington and Sims. It had a single cylinder 9½ inches in diameter with a 12-inch stroke, and made about 270 revolutions per minute. The engine occupied a floor space 100 inches by 60 inches, and weighed 4,500 pounds. The initial steam pressure seldom exceeded thirty pounds per square inch, and this pressure was not always maintained, especially in port. The engine bed was heavy, solid and stiff, and took the bending stresses of the guides at its upper surface. Two main pillow blocks carried the steel crank shaft and supported the two wheels, one of which was the fly-wheel, and the other the pulley over which the belt to the dynamo ran. The steam cylinder was overhung with the exhaust pipe leading down to the deck. The crank pin was oiled by a "wiper," while sight feed cups supplied the remainder of the lubrication. Oil for the plant was obtained from the Vacuum Oil Company. Mineral oil was used entirely, that for the engine being 600 W Cylinder Oil and that for the bearings Electric Machinery Oil. Both oils cost





Governor and Eccentrics Minimum Throw Governor and Eccentrics Maximum Throw.

sixty-five cents a gallon. It was found unnecessary to use sperm oil on the bearings of the dynamo.

A piston valve with a double port was used with this engine so that approximately boiler pressure was admitted to the cylinder and continued to the point of cut-off with practically no wire-drawing of the steam. This lack of wire-drawing was a very unusual feature in engines at that time. The use of the double ported valve enabled the clearance to be kept down to about 5 per cent. This low clearance was also unusual in an engine where the diameter of the cylinder bore such a large relation to the length of the stroke.

The governor on the Armington and Sims engine was of a novel and ingenious type.

Two weights "1" were carried on and formed a part of the arms pivoted to the governor pulley. The position of these weights as determined by the speed and the action of the springs, determined the position of the eccentrics "C" and "D," and thus the position and motion of the valve and the point of cut-off, flying out and giving a higher rate of expansion as the load on the engine diminished or as the steam pressure rose. The eccentric "C" was set inside the eccentric "D" and connected to the governor arms in such a way that as the weights separated or approached each other, the eccentrics were turned on the shaft so as to cause their throws to coincide or to oppose each other. The action was almost precisely the same as that of a Stephenson link operating between full and mid-gear. The range of action gave very close governing between zero and three-quarters stroke. The action of the governor was tested on board at one time by suddenly throwing off about half load. No perceptible change in speed was noted on the engine.

No figures are available as to the power delivered by this engine on test, but a little speculation is rather interesting. The rated full load on the generator with all lamps burning was about 14 KW. (18.75 H.P.). Assuming 90 per cent efficiency of the generator, which efficiency was obtained on similar machines, the engine had to deliver a little over 20 H.P.

If we assume a thirty-pound initial steam pressure, which the ship's officers said they did not always get, an eighteen-inch vacuum, which was about the average obtained, 5 per cent clearance and 20 per cent compression which this type of engine usually used, and cut off at 50 per cent of the stroke, the theoretical mean effective pressure will be a trifle over thirty-one pounds. If we assume a diagram factor of .7, which is attained on small fast-running engines of this type, the mean effective pressure was a trifle less than 22 pounds.

At 270 r.p.m the horsepower developed equaled

$$\frac{2 \times 270 \times 22 \times 70.88}{33{,}000} = 25 +, \text{H.P.}$$

Thus there was ample power to carry the full load of the generator even with the engine cutting off at half stroke.

The installation was made under the supervision of Mr. Miller F. Moore, formerly an engineer in the Navy, and at that time General Manager of the Edison Company. Carpenters were used to run the wire in as they were needed to make a good job on the moulding.

The good design and workmanship of the engine and the care it received on board the *Trenton* are indicated by the fact that during fifteen months' use the only renewal necessary was a set of crank-pin brasses.

The engine and dynamo belted together occupied a floor space of 101

square feet, and weighed ten thousand, five hundred pounds. It is interesting to note that the 500 KW. turbogenerators to be installed on the battle cruisers will take up a floor space of but 106.5 square feet, although they will weigh forty-six thousand pounds. The advance of electrical engineering is well shown in this development from 15 KW. to 500 KW. in practically the same floor space.

The switchboard for the *Trenton's* lighting plant was located near the bulkhead in the after end of the dynamo room. It was massively built of slate with the bus bars on the front, and on it were mounted the circuit switches for the various lighting circuits of the vessel. No voltmeter or ammeter was fitted to the board, as the development of these instruments had not progressed to the point where they would operate satisfactorily aboard ship. The voltage at the lamps was regulated by the eye, being adjusted to give less candle-power than their rating in order to prolong their life. The 16-candle-power lamps were adjusted to give 12-candle-power as closely as could be determined. The efficiency of the lamps was not considered, as the predominant desire with this installation was to show reliabilty as compared with oil lamps, and long life of the lamps was secured by burning them at a low candle-power. Even 12-candle-power lamps as compared with oil lamps were such an improvement that apparently no objection was raised to the lower rating.

An automatic voltage regulator was furnished with the dynamo, but its use was discontinued after six months. This regulator consisted of a rheostat in the field circuit which was automatically shifted by a solenoid when the current in the external circuit rose or fell due to an increase in the number of lamps in use. As the generator was a shunt machine, additional current in the external circuit would cause the voltage to fall off. With the automatic regulator, additional current would move the solenoid, cutting out field resistance, and by allowing additional current to flow in the field, bring the voltage up again.

Reports from the ship indicated a belief that failure of lamps was due to the use of this regulator. No explanation was offered for this belief, but it may be supposed that the regulator failed to reduce the voltage when the load was decreased. This excess voltage would tend to decrease the life of the lamps considerably.

The switchboard was fitted with switches for the following circuts: spar deck, gun deck, berth deck, orlop deck, wardroom and admiral's quarters, fire and engine rooms and holds.

These main circuits were of number 12 or 14 single conductor cable (6,530 or 4,107 circular mils). They were led about the ship in pine mouldings. These mouldings consisted of battens with two grooves for the mains over which a cap was fastened with screws after the wires were run. When well painted, this moulding was fairly watertight.

For the branch wires, number 18 (1,624 circular mil) wire was used. This was run in a smaller moulding with grooves, which was screwed to beams and bulkheads. Much trouble was experienced with salt water getting behind this moulding and rotting the insulation of the branch leads.

The wire for the mains was a single strand, tinned and covered with rubber insulation. That for the branch leads was for the most part untinned and covered with cotton insulation and painted. A small number of the branch leads were tinned and insulated with rubber, which later proved to be of very inferior quality. The wire for the portable deck lanterns and

engine-room portables was twin conductor, two fine flexible wires being surrounded by gutta percha covered with jute braiding. This wire was very unsatisfactory as the gutta percha hardened and became brittle in cold weather so that it cracked off, and in warm weather softened sufficiently to allow the wires to come into contact with each other and cause a short circuit.

The mains were fitted with numerous cut-out boxes from which three or four lamps were controlled. The boxes were fitted with fuses to protect the mains.

More trouble was experienced from defective wiring on the *Trenton* than from any other part of the electric plant. Salt water was as great an enemy to her simple plant as it is to our complicated system of to-day. Wires were frequently found entirely corroded through from the action of the salt water and the copper reduced to a greenish powder. The resistance of this powder was high enough so that with the ordinary currents flowing which would not blow a fuse, enough heat would be generated to set the moulding on fire.

The Edison lamps were fitted about the ship in ceiling fixtures, bulkhead standing lights, electroliers, and bracket fixtures, very much as they are to-day. Reading lamps and a cigar lighter were furnished for the wardroom. Portables were furnished for use on deck, in staterooms, and in the engineer department. Running lights, anchor lights and gangway lights were fitted. The running lights had two lamps in each box, fitted with a relay which would cut in the second lamp if the first one failed. This automatic feature was not a success, however.

A night signalling set was devised, using deck lanterns. Two lamps were hung a certain distance apart, depending on the distance of the ship to which the signal was made, and connected to a keyboard with two keys. By pressing one key, one lamp was lighted, and by pressing the second key, both lamps were shown. By means of the Myer code, signals could be sent accurately and rapidly.

An illuminating set for the quarter deck was constructed by stringing one hundred sockets on a cable. This set was tried out on July 4, 1884, and contributed materially to the brilliancy of the occasion.

A deep-sea lamp was fitted up with eighty feet of cable for use over the side.

The lamp sockets were secured to the fixtures by set screws, as were the shade holders. They frequently worked loose, due to vibration. One wire inside the lamp socket was soldered into the ring into which the lamp base screwed. This soldered joint frequently carried away.

On the trip across the Atlantic soon after the lighting set was installed very heavy weather was encountered and the ship worked a great deal. This caused considerable trouble with the wiring, but the fuses prevented serious damage.

Many of the lamp sockets were attached to the fixtures with spiral springs, and the mortality of lamps in these sockets was much less than in those rigidly screwed to the fixtures.

Many lamps gave a life of over five thousand hours. Much of this longevity was due to operating the lamps at a lower candle-power than their rating; life being obtained at the expense of efficiency. At first the expenditures of lamps was very high, but it was gradually reduced as witness the expenditure during the year 1884:

Lamps expended first quarter 1884	334
Lamps expended second quarter 1884	78
Lamps expended third quarter 1884	65
Lamps expended fourth quarter 1884	50

Lamps were lost from various causes. Of the last fifty lamps expended, five were of defective construction such as bad connection of the carbon filament with the copper wire inside the lamp, and broken wires inside the plaster of Paris; fifteen were accidentally broken; and remainder broke down from short circuits and inherent defects which shortened their life.

The objection to electric lighting on account of its not standing the shock of gun fire proved ill-founded. During the first quarter when target practices were held not a lamp or shade of the electric plant was removed, and but one lamp was broken. This lamp was eighteen inches from the breech of a gun when run in and was not fitted with a spring fixture.

The successful operation of the electric plant on the *Trenton* was due to the constant supervision of the officers in charge of the equipment. Lieut.-Commander Bradford, who supervised the installation of the plant and who was in charge at first, and Ensign E. H. Tillman (now Comdr., U.S.N., Retired), who succeeded him, were indefatigable in their efforts to keep the plant in efficient condition. They made many valuable reports which formed the basis of specifications for the generators, wiring and lamps for subsequent electric plants.

The lighting of men-of-war by electricity was proven practicable, and the experiment was such a success that the question was settled in our service.

The *Trenton* was re-wired in 1887 at the end of her cruise, great attention being paid to the insulation of the circuits. Thirty-nine new lamps were added, and the fixtures repaired and re-polished. The dynamo and engine were found in excellent condition.

The plant continued in successful operation until the *Trenton* was lost in Samoa in March, 1889, the dynamo continuing to run until the fires under the boilers were extinguished by the incoming water.

THE INFLUENCE OF SEA CONDITIONS ON THE SPEED OF SHIPS

EDWARD V. LEWIS

THE AUTHOR

After receiving his B.A. degree in mathematics from Nebraska Wesleyan University in 1935, the author studied naval architecture at the University of Glasgow. He then joined the design staff of George G. Sharp, Naval Architect, New York, where he remained until going to Stevens Institute of Technology in 1951. Mr. Lewis is now in charge of research on Surface Ship Hydrodynamics at the Stevens Experimental Towing Tank. He recently received the degree M.Sc. in Naval Architecture from Webb Institute of Naval Architecture and is a member of the Hull Structure Committee of the Society of Naval Architects and Marine Engineers.

INTRODUCTION

There can be little doubt that the most pressing present-day problem of Naval Architecture is how to increase ship speeds, particularly in rough weather. Speaking as one who is fond of the sea and ships, but has had little opportunity for actual voyaging, the writer feels that the sea speed of ships is also the most fascinating problem in Naval Architecture. There is real vicarious enjoyment in the study of the logs of stormy voyages, in the examination of charts showing ocean winds, seas and currents, in experimenting with models of ships in the waves of a model basin, and in the use of mathematical tools to describe both the sea and a ship's motions in it. Indeed the desk-bound voyager has certain advantages over the bona-fide one in that he does not have to stand on the bridge in sub-zero weather, buffeted by a North Atlantic gale to observe the sea. And no matter how violent the motion of the ship, he is in no danger of becoming seasick!

The problem of ship speed is particularly important, of course, for naval vessels of all types. (Fig. 1). It is also important for cargo and passenger ships. On the one hand, peacetime commercial requirements are gradually requiring greater ship speeds; on the other hand, military considerations demand even higher speeds in order that such vessels can be safely operated in an emergency. The problem is highlighted by the recent successful trials of the first atomic submarine. The possibility that unfriendly nations may also in time possess such craft, emphasizes the need for higher speeds for both cargo ships and for escort vessels, so that the trade routes of the world can always be kept open.

For underwater craft the problem of

Figure 1a—U.S. Coast Guard Cutter in heavy sea

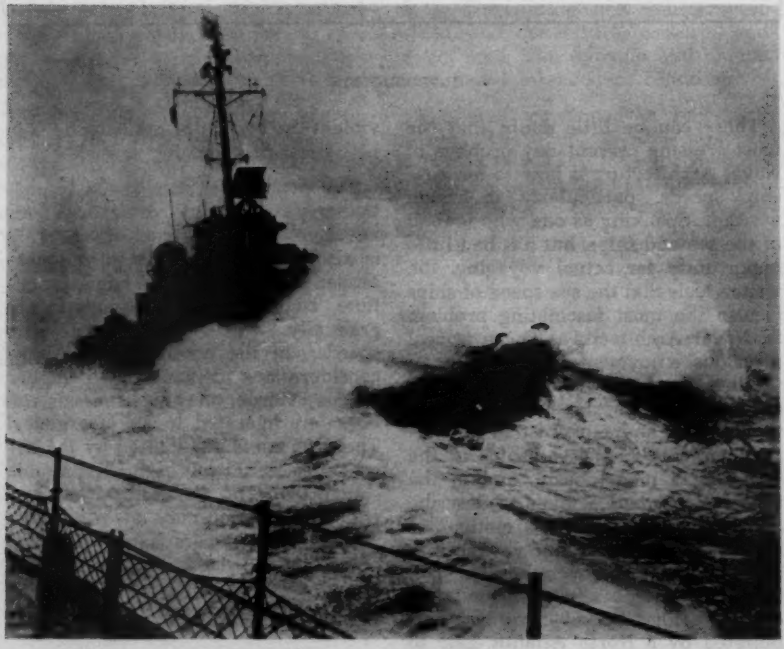


Figure 1b—U.S. Destroyer in heavy sea. (Official U.S. Navy Photograph)

speed has been greatly simplified by the harnessing of atomic energy, thus opening up almost unlimited possibilities of increasing the power available for propulsion. Surface craft, on the other hand, are somewhat at a disadvantage from the hydrodynamic point of view, even if atomic power were applied to their propulsion. This fact results from the rapid growth with increasing speed of the wave system created on the surface by the ship's motion. However, with sufficient power available, there are ways of overcoming wavemaking resistance in calm water; the real difficulty arises when we consider the nature of the ocean surface—always disturbed to greater or lesser degree by winds blowing across it. Sea conditions have already imposed severe limits on the average speeds of many types of conventional ships on the stormier ocean routes, and simply installing more power is not the answer.

It is the object of this paper to describe some of the problems of increasing the speed of surface ships in the face of the opposing forces of wind and sea. Since the days of the Phoenicians and the Vikings, of Columbus and Magellan, man has stubbornly fought the ocean in ships. Now he is mustering the forces of modern science and engineering to gain from Neptune not only safe but ever swifter passage across the seas.

THE OCEAN

The logical starting point for this discussion is the ocean. There has been rapid development of theory and knowledge of the surface characteristics of the sea during and since the war—mainly as the result of the military need for methods of forecasting sea and swell conditions far in advance. In the past it had been thought that sea conditions could be adequately described by average wave lengths and heights associated with different wind conditions. Until recently the only ocean wave data available to the Naval Architect were in this form. Recent developments have shown, however, that the old assumptions may be misleading, for the most prominent characteristic of storm seas is their irregularity.

The new approach to the observation and description of the sea involves the use of statistical methods, and they have been applied not only in this country but in England and France, with highly successful results. Our particular task is to simplify the theories that have been developed by oceanographers and reorientate them to apply to our problems of ship speeds.

Sample records of the ocean surface at a fixed point are shown in figure 2. Such records are obtainable from a pressure recorder on the bottom in shallow water, for example, or by means of a long floating "wave pole" in deep water, with instruments for recording the water elevation in relation to it. The first record (a) is typical of the sea surface in a storm area, where the wind has been blowing for some length of time. It is characterized by an appearance of great irregularity and confusion, with wide fluctuations in the intervals between crests and in the wave heights. Records (b) is typical of a "swell," the sea surface after a storm has passed or at some distance from a storm. It is still irregular, but not nearly so much so as the other record. Both of these records—even the apparently chaotic first one—are found to be amenable to analysis statistically because of a very important observed fact. To explain this fact the record is first marked off at equal small intervals of time, as shown in

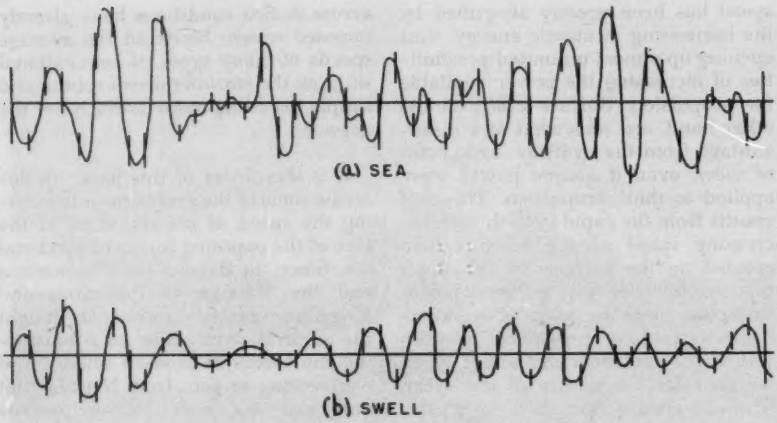


Figure 2—Typical ocean wave records, at fixed point

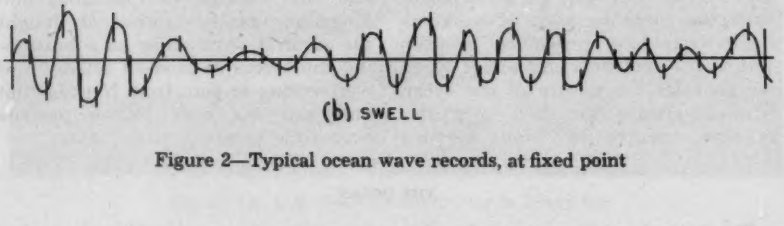

+ POINTS OBTAINED FROM ANALYSIS
NORMAL DISTRIBUTION CURVE
FREQUENCY OF OCCURRENCE
SCALE OF DEVIATIONS OF POINTS ON RECORD FROM MEAN

Figure 3—Typical frequency distribution of points on an ocean wave record. Note: This graph was prepared from data given in Ref. 1, based on 200 points in a 25-min. record obtained from a pressure type wave recorder.

figure 2, and the deviations of the points from the average line are classified and plotted on the basis of frequency of occurrence. It is found then that the result is very close to a typical "normal" distribution curve, as shown in figure 3. The distribution curves will be different for different wave records, but they are always found to be very close to the typical shape.

Starting from this important characteristic of ocean wave records, Professor Pierson and his co-workers at New York University have found that the sea surface can be represented as an infinite number of infinitesimal sine waves superimposed in random fashion, so that all of the crests never coincide (Ref. 1). As a practical matter, the elevation at any instant may be considered as the sum of points on a large number—instead of an *infinite* number—of sine waves of very small amplitude. This picture may be visualized by assuming a large number of corrugated plates, each with a different sized corrugation, stacked on top of one another. The composite wave pattern can then be obtained by adding the heights of points on the plates vertically in line. Each of the component waves possesses the well-known characteristics of simple surface waves whereby the wave is completely specified by its frequency (or period) and its height, since wave length and velocity are known functions of frequency (or period). However, these component waves are not directly visible in a seaway or a record; they can be found only by a rather complicated analytical method.

The frequencies or periods of the component waves and their relative importance in an actual wave record are described by the "energy spectrum" of the seaway. For the case of a reasonably steady wind blowing over an initially calm sea for a sufficient length of time in the open ocean, Professor Neumann of New York University has obtained a mathematical expression for this spectrum, which can be worked out for any desired wind velocity (Ref. 2). A typical example is shown in figure 4(a), in which the curve simply indicates the relative amplitudes or heights of the many wave components present in a typical ideal seaway. In this figure it is shown how the wave pattern is approximated by taking the sum of say 14 component waves, neglecting the low waves at each end. The frequency and hence length of each component is indicated by the position of one of the narrow rectangles along the ordinate scale of fraquencies, ω, (or periods, T), and the amplitude of each component is given by the square root of the area of the same rectangle. In figure 4(b) the 14 components corresponding to each of the rectangles are shown—the "corrugated plates" previously mentioned. Summing up the heights of these components at successive instants will give a typical wave pattern similar to figure 2(a). And, of course, the greater the number of components taken, the more exactly the pattern will approximate a possible ocean wave record. However, no two records —either artificial or real— will ever be exactly alike, even though their statistical properties may be identical.

Parenthetically, for those interested in the mathematics, the representation for this sum of infinitesimal sine waves, derived from work on the analysis of random noise in the field of communication engineering, takes the following rather wierd form:

$$r(t) = \int_0^\infty \cos[\omega t + \varepsilon(\omega)] \sqrt{[r(\omega)]^2} \; d\omega.$$

The integral, known as a Lebesgue energy integral, is purely symbolic and can be evaluated only as a partial sum of a large number of terms. The cosine factor provides the oscillating character of the component waves, being the "circular" frequency $2\pi/T$, where T

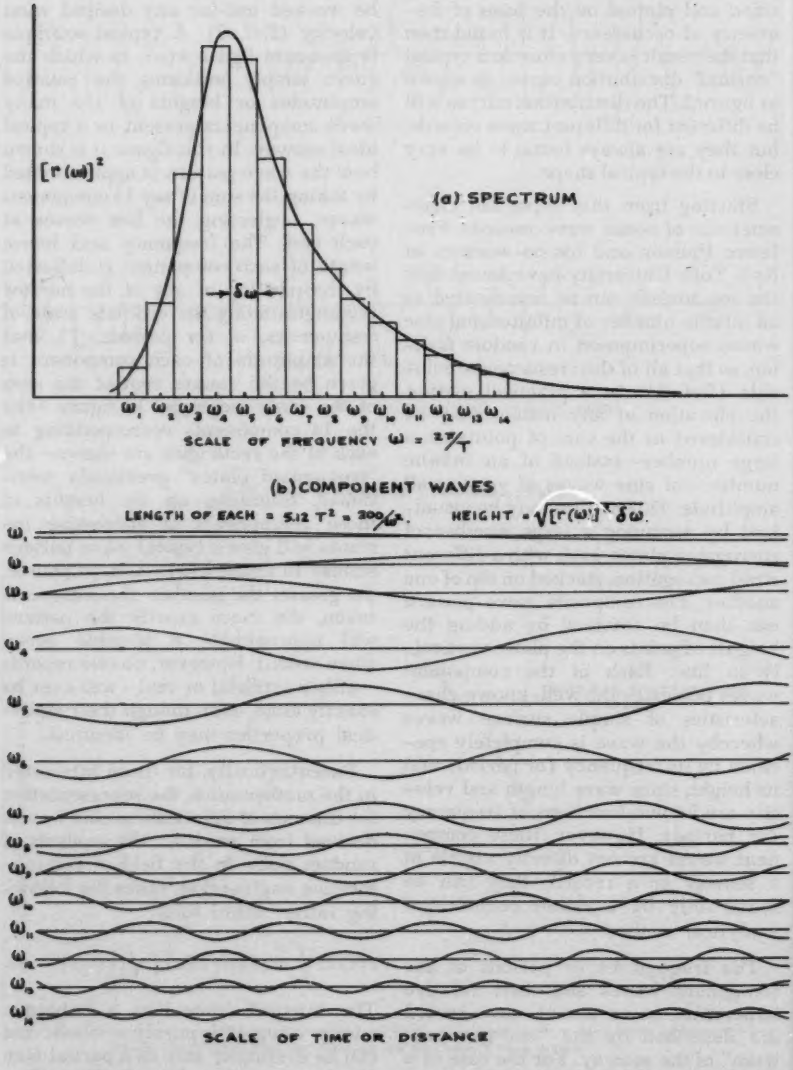


Figure 4—Typical energy spectrum—showing approximation by a finite sum of components.

is the period. The term $\varepsilon(\omega)$ is the phase lag, having a random value between 0 and 2π for each value of ω; it is this random phase which causes the distribution of $r(t)$ values to have the necessary Gaussian or normal character. The radical $\sqrt{[r(\omega)]^2}\, d\omega$ represents the amplitude function, which when a finite number of terms are used gives finite amplitude values for each component wave. A plot of the quantity $[r(\omega)]^2$ vs. ω is termed the energy or power spectrum (fig. 4(a)), and its shape serves to characterize the sea condition recorded. This particular form of the amplitude function comes about as a matter of convenience, since it can be shown that the mean square value of the record of $r(t)$ (i.e. the variance) is equal to one half the area under the the power spectrum $= \frac{1}{2}\int_0^\infty r(\omega)^2\, d\omega$. In other words, the properties of the components of the seaway may be used to define the properties of the wave pattern. The energy spectrum of an actual record may be obtained by the process of auto-correlation, since it can be proved that (apart from a constant factor equal to the area under the spectrum) the spectrum is equal to the Fourier cosine transform of the auto-correlation function. (For further details, see Refs. 1&2)

The energy spectrum is different from the ideal, however, if the wind has not blown long enough for the sea to be fully developed, or if the open sea distance or "fetch" over which the wind has blown is limited. The spectrum grows from the high frequency end, and in incomplete form it would terminate at some frequency—say ω_7 in figure 4—determined by the duration or fetch. Hence, the spectrum of a simple storm appears to be a fairly definite function of wind velocity, duration and fetch.

So far no mention has been made of the direction of motion of the waves. Actually it appears that the wave components are not all travelling in the same direction—as a result of fluctuations in the storm winds which created them. That is, the corrugated plates previously mentioned lie at different angles to one another. This results in the characteristic "short crestedness" of ocean storm waves in a direction at right angles to their motion. However, it is believed that most of the components lie within $\pm 30^0$ of the direction of motion of the dominant crests—when we are considering the disturbance created by a *single storm*. The theoretical form of three-dimensional spectra have been tentatively worked out, thus permitting the mathematical representation of the sea surface over an area as well as at a fixed point, but we shall not consider this complication here.

Pierson's theory of the decay of storm waves and the formation of swell is of particular interest. Consider a train of storm waves having a normal spectrum passing out of the area of high wind in which it was created. A sorting out process or "dispersion" begins at once, as a result of the differences in velocity of the different frequency components. The first waves to reach a point some distance away will be composed of the lower frequency components (i.e., long, fast-moving waves). This means the spectrum has become narrower and the waves more regular. (See figure 2(b)). At greater distances the spectrum will be further narrowed down (or filtered). A typical swell spectrum will consist of 2 or 3 of the rectangles of figure 3. With the passage of time, shorter waves corresponding to higher frequencies will successively appear. There is a gradual reduction in wave heights as a result of this dispersion and a further reduction as a result of the fact that the wave pattern spreads as it travels. Nevertheless, oceanographers believe that the disturbance created by one storm can easily cross the entire width of the

Atlantic Ocean, for example. Consequently, as is generally observed, new storms in winter are always acting on water already affected by previous storms. A typical condition would seem to be a storm sea superimposed on a swell, each having a different average direction. Theoretically the spectrum of the combined disturbance is intially simply the sum of the spectra of the two separate wave trains. From the combined spectrum, the mathematical representation of the typical surface elevation can be obtained to any desired length. More information is needed on the characteristics of actual storm spectra.

To summarize, modern developments in oceanography indicate that storm seas cannot be approximated by a single average wave length and height but must be considered as composed of the sum of a large number of different waves covering a wide range of frequencies or periods and of varying relative heights.

Figure 5—A Cruiser meeting rough seas in the North Atlantic. (Official U.S. Navy Photograph)

FACTORS AFFECTING SHIP SPEED

We come now to the problem of the ship moving across the complex ocean surface just described. A ship tied up at a pier impresses one as a rather complex engineering structure — a combination of warehouse, hotel and power station. But struggling against elemental forces, moving steadily ahead through an ocean storm, it acquires vitality and life. It is able to move forward, except perhaps in the strongest gale, because it yields to the sea in respect to secondary motions such as pitch and roll while perserverving in its forward movement.

Speed reduction in heavy weather results from two types of influence. The first is the direct effect of the added resistance to forward motion caused by the action of wind and waves. The second may be termed indirect and refers to the necessity of voluntary reduction of power—and hence speed—to reduce the violence of the secondary motions. (See Fig. 5)

Let us consider first of all the direct effects of waves and winds on increasing the resistance. This added resistance results from the following:

(1) Wind resistance—the magnitude of which has been well established for different ship types,

(2) Wave reflection effects—the increased resistance caused by the distortion by the moving hull of the encountered waves (Ref. 5),

(3) Effect of rolling—a factor which is comparatively small,

(4) Effect of heaving and pitching—an oscillating fore and aft force resulting from the motion being out of phase with the wave, this force having a net component aft (Ref. 4). This effect has been studied in model tests and theory for regular waves only; extension to complex seas is needed.

(5) Finally, the indirect effect of the added resistance on propulsion—this is not serious in itself for a turbine driven ship, if the propeller remains well immersed.

In good weather trade routes and for a considerable portion of the time on even bad weather runs, the above added resistance considerations are basic. However, the other group of factors becomes increasingly important as sea conditions grow worse—these are the indirect effects of motions on speed. For every ship there are limiting sea conditions beyond which the power must be reduced in order to ease the motions of the vessel. Even the new "United States" must reduce power in heavy weather, and it is reported that the most comfortable condition for the "Queens" in really rough going is to turn and run with the sea, which they sometimes do if necessary for passengers' comfort.

To illustrate the relative importance of the two types of factors affecting speed, let us refer to figure 6. We have recently analyzed some log data for typical cargo ships in winter North Atlantic service—north of the British Isles to Scandinavia—undoubtedly the most severe of the important trade routes of the world. The graph shows first the expected trend of ship speed with increasing average wave height,

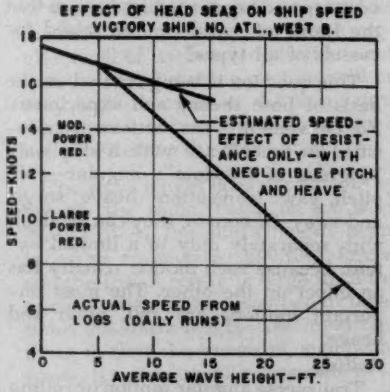


Figure 6

if full power were maintained and only the added resistance effects were taken into account—with negligible pitching and heaving. The other steeper line shows the actual trend of speed found by plotting average daily speeds from log records. The difference between the two lines is due to the added resistance resulting from ship motions and to the voluntary reduction of power made necessary by the violent motions of the ship.

Thus it is clear that simply increasing the power of ships is not alone the answer to our problem of speed. The effect of motions on speed involves many factors — gleaned from log records, discussions with officers, and from the reports of a comparatively small number of voyages in which actual data have been taken (reference 3). Although different people stress different things, the effects of motions may be classified as follows:

(1) Effects of amplitudes of motions (and phase relationship with encountered waves):
- Shipping water—with danger to fittings and deck cargo,
- Pounding and slamming—with danger to structure,
- Racing of propeller — with reduced efficiency of propulsion,
- Difficulty in steering—with danger of being unable to maintain the desired course.

(2) Effects of accelerations:
- Shifting cargo,
- Dislodging objects on board, furniture, etc.,
- Discomfort and danger to passengers and crew.

This is one field in which more qualitative data are needed, for strange to say, very little is known exactly as to what are the limits of amplitudes and accelerations which are acceptable on different types of ships.

SHIP MOTIONS

Assuming that criteria on allowable amplitudes and accelerations will be forthcoming in the near future, the most urgent problem of ship speeds narrows down to the problem of motions. How can we determine them in advance and hence modify them so that the limits of speed can be raised for vessels of all types?

This question is being studied on the basis of both theory and experiment. For convenience, the motions are classified in accordance with a ship's six "degrees of freedom": angular—roll, pitch, yaw; translation—heave, surge, and sway. Of course, they can be dealt with separately only to a limited extent, because each motion usually has an effect on the other. The most important motions are roll, pitch and heave.

Rolling

Transverse angular motion or rolling has received the greatest share of attention, and from the point of view of the present discussion of speed, it may be considered to be understood. Rolling in a regular swell is a forced simple harmonic oscillation—excited by harmonic wave forces and resisted by small damping forces (wave making and viscous). The ship has a natural frequency of roll depending on its geometry and weight distribution, and when the exciting forces are tuned to this frequency, large resonant rolling can result. In regular waves a small change of course or speed usually suffices to avoid the synchronous roll.

When the waves are *not* regular, however, the rolling is *not* in general regular or harmonic. But observations at sea show that as the rolling becomes heavy in rough storm seas, the period does begin to approximate the natural period of roll (ref. 10). In such conditions, the amplitudes vary widely, however, and "beats" are often ob-

served. The explanation for this behavior lies in the fact discussed above that a rough sea contains a wide range of frequencies, modified of course by the ship's speed and direction. The exciting wave forces act upon an oscillating system—the ship—which has a sharply tuned response curve—with the peak at its natural period of roll. Consequently, ships at sea single out the resonant frequencies and roll predominantly in their natural period. Under such sea conditions, it may be difficult or impossible to avoid heavy rolling by a change of course or speed.

But from the point of view of ship speed, it may be said that rolling is not a serious problem. First, rolling does not itself have a very great effect on resistance. And second, the use of stabilizing fins seems to have made it possible to reduce rolling very drastically. The idea of fins appears to have been worked out independently in 1889 by Thornycroft in England and Motora in Japan. In the last few years they have been successfully installed in a large number of ships in the form of the Denny-Brown stabilizer.

The stabilizing fins are simply hydrofoils projecting laterally, one on each side of the ship, pivoted about a horizontal transverse axis. They are arranged to hinge in opposite directions, so that when the ship is moving ahead the fin on one side can be made to exert a downward force while the one on the other side is exerting an upward force. The most important element of the installation is the control system, which is based on two gyroscopes. One gyro responds to the angle of roll and the other to the velocity of roll. This combination provides prompt change of position of the fins so that corrective action is applied before an appreciable roll can develop. As a consequence, fairly small forces suffice to reduce the roll to a marked degree. Improved methods of control for stabilizing fins are being developed.

Pitch and Heave

We come now to the most important aspect of ship motions in respect to speed: the motions of heave and pitch. Although the distinction between these two types of motion is an artificial one and they normally interact on one another, the concepts are quite definite and very useful in analysis. Heave is the vertical movement of the ship's center of gravity; pitch is the angular motion of the ship in a vertical fore and aft plane.

The question arises: why should speed be governed by the violence of pitching and heaving motions? In particular, why does a reduction of speed usually make a ship more comfortable? The absolute value of the added resistance due to waves is found both theoretically and experimentally to be affected very little by the ship's speed. Why shouldn't the motions show the same small effect? If we know the answer to these questions, perhaps we can find other ways to ease the motions than by reducing speed.

It so happens that observations show the most important wave lengths in storms at sea to be of the same order of magnitude as the lengths of ships, so that large exciting forces are always present in rough weather, regardless of speed. Considering as an example the case of a ship heading into a regular swell of its own length, it is clear that the forces causing pitching will be very high—because at the same time that a crest is pushing the bow up, a hollow is letting the stern drop.

The wave length does not have to be exactly the same length as the ship. Waves of ¾ the ship's length begin to cause appreciable exciting forces, and the forces continue large until the swell is much longer—say two or three times the ship's length. The important thing is that the range of significant wave lengths usually present in a storm wave pattern covers the normal

range of ship lengths—including that of even the Queen Elizabeth in a bad storm. And these length relationships are unchanged by the speed of the ship, for no matter what its speed, when the crest of a wave is at the bow, the hollow will be at the same position at the stern. On the other hand, if the ship meets the waves at some direction other than head on or directly astern, the effective lengths of the waves will be increased, and therefore the shorter waves will be more important. Although some particular heading may result in reduced exciting forces, change of speed does not have this effect.

The reason for the influence of speed on pitching and heaving then is in the period relationships—as in the case of rolling. It is the combination of large exciting forces *plus* resonance which seems to give the really violent motion. We shall discuss this important matter first for a ship in uniform waves—closely approximating a swell condition at sea. This simple case has been studied both experimentally and analytically. Pitching will be considered, but the picture with respect to heaving is analogous.

The significant thing about speed is that it affects the period of the exciting forces—i.e., the period of encounter with the waves. If the ship speed is 0, the period of encounter in a regular seaway will be that corresponding to the wave velocity past the ship. As the ship is given forward speeds against the waves, the period of encounter becomes less. (In a following sea, it becomes greater). Although the pitching will always be heavy in waves near the ship length, it will reach its greatest value in the vicinity of the speed giving synchronism between the period of encounter and the ship's natural pitching period. It so happens that for most ships in waves of their own length this condition occurs somewhere near their normal speeds; consequently a reduction in speed ameliorates the situation.

There is another equally important consideration, and that is the phase relationship between the regular waves and the motion. It is well known in the theory of oscillations that at synchronism a lag of 90° in phase is characteristic between the applied force and the response— for moderate damping. For the normal ship with almost vertical sides this applies closely and results in a situation shown clearly in model tests, in which the ship at synchronism pitches down into the crest, usually shipping green water even in waves of moderate height. See the model photographs in fig. 7.

A reduction of speed from that giving synchronism serves not only to reduce the amplitude of motions and accelerations, but it changes the phase relationships so as to keep the decks drier. The ship follows the wave slope instead of going against it. Figure 8 shows these phase relationships for a typical merchant ship in regular waves of length equal to the ship length. (See also Ref. 9).

The possibility remains of increasing the speed to avoid serious resonance. For a high-powered vessel in a regular swell this may well be possible, so that the pitching becomes less severe as the speed is either increased or decreased.

Pitch and Heave In An Irregular Sea

We come now to the situation of a ship pitching in a complex storm sea—a problem which is just beginning to be studied in detail using the new theories and methods (ref. 11). But first some clarification is needed regarding the wave lengths found in irregular storm seas. For a regular wave —such as can readily be created in a model tank—there is a definite relationship between period (or frequency) and length, but such is not the case in an irregular sea. Neither

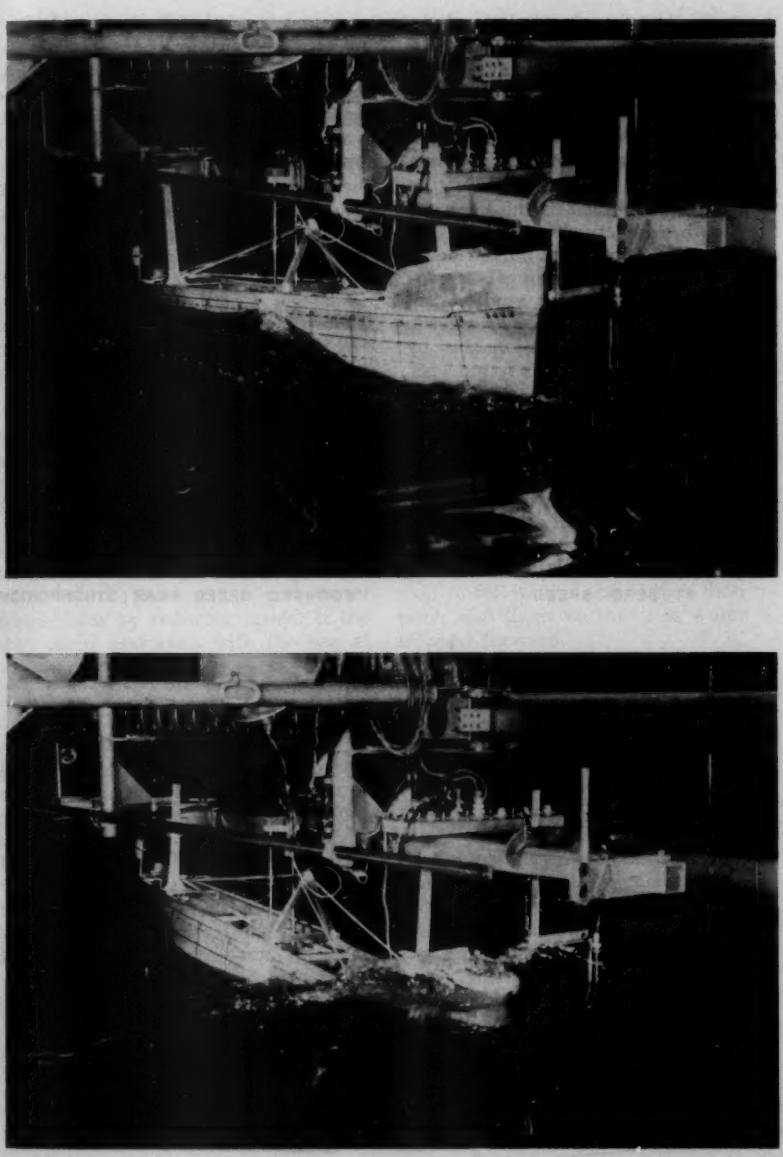


Figure 7—Model at speed for synchronous pitching in head seas of length equal to model length. (SNAME Project S-3)

the wave lengths nor periods of the component waves previously discussed, and illustrated in fig. 4, are directly observable in the seaway. Only the combined effect of the super-imposed components can be seen. But it is possible to observe and record the apparent periods and wave lengths, which can be defined as the time and the length, respectively, between succesive crests observed at a fixed point. The statistical distribution of such apparent periods has been studied, but not of wave lengths. However, we can get an idea of the relationships by considering averages. It is found (ref. 2) that for a fully developed sea corresponding to a 40 knot wind, the most important period (the peak of the energy spectrum) is 16.1 seconds and the average apparent period is 11.4 seconds. The wave length corresponding to the first would be 1330 ft. and to the second 670 ft. But the average apparent wave length is only 450 ft. The theory indicates that it is the periods and lengths of the wave *components* which are of basic significance for ship motions, and direct relationships to the *apparent* periods and lengths have not yet been established. However, the existence of apparent wave lengths near the ship length indicates that exciting forces and moments are high.

DIAGRAM SHOWING TYPICAL PHASE RELATIONSHIPS BETWEEN PITCHING MOTION AND WAVE OF SHIP LENGTH

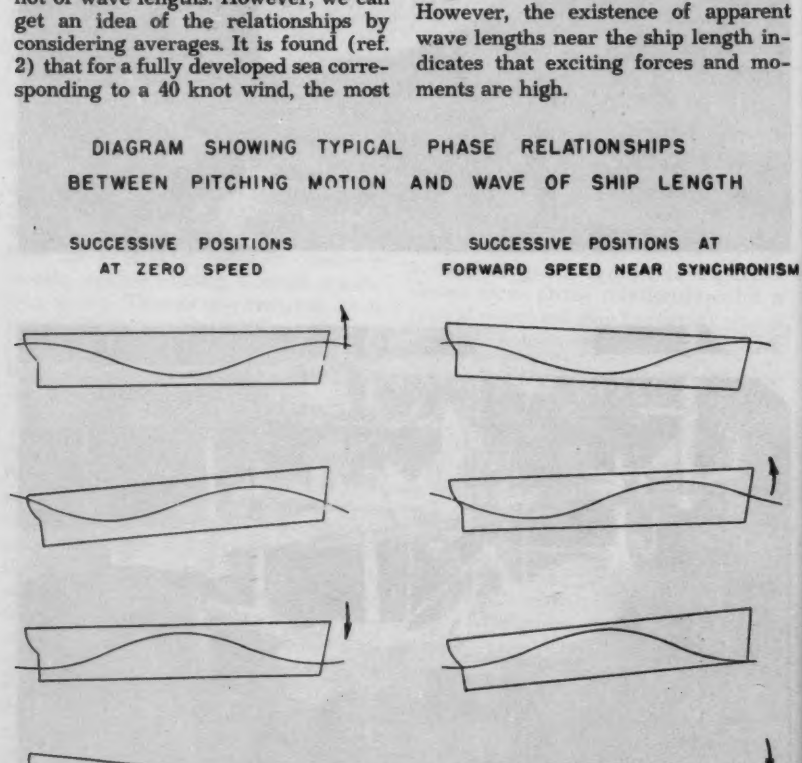


Figure 8

It is safe to say then that if there are component wave lengths near the ship length present in a seaway—which as we have seen is always the case when the sea is rough enough—there will be appreciable irregular pitching. If, further, the ship's speed and heading give periods of encounter with these components which are near the ship's natural period the pitching will at times be more violent. Sea observations show this to be the case in storms, with motions tending to follow a period of oscillation close to the natural period, but with great irregularity in amplitudes. (Ref. 10).

The significance of all this for ship speed is that (1) it is impossible to eliminate pitching and heaving when heading into a bad storm, because wave lengths near the ship's length cannot be avoided, (a change of course may be helpful in some cases). (2) It is usually possible to avoid synchronism with the most serious component frequencies by reducing speed. If the ship turns and runs with the sea at slow speed, the frequencies of encounter with important components will be removed still more from synchronism. This is no doubt one of the reasons that books on navigation suggest that steamships heave to with the stern to wind and sea.

On the other hand, if speed is increased in an irregular storm sea, resonance will occur with lower frequency (longer wave) components present, which may be equally important. Hence, pitching can be reduced by *increasing* speed only in moderate seas or in a short swell.

Thus in really bad weather a ship heaves to, with speed near zero, heading into the sea or nearly so. Or the ship may turn and run with the wind and sea. Pitching and heaving are then much less severe, since synchronism with the waves having the largest exciting forces are avoided. An additional favorable effect is the tendency of the ship to follow the seas rather than to pitch into them, so that less water is shipped forward.

RESEARCH IN SHIP MOTIONS

The experimental and theoretical study of ship motions is making significant progress toward further understanding of the above phenomena of pitch and heave in actual sea conditions. The new technique has been developed largely by Mr. M. St. Denis of the David Taylor Model Basin, in cooperation with Professor Pierson of New York University (ref. 11). Significant contributions are also being made by Fuchs and MacCamy at the University of California (ref. 12). The distinctive feature of these methods is the hypothesis that motion in a confused sea need not be considered as a succession of transients, but as the linear summation of responses to the very large number of regular component waves. This theory has not yet been fully confirmed, but it offers real promise. It has incidentally given added impetus to the theoretical and experimental determination of ship responses in regular waves of a wide range of frequencies. Such studies are important not only as an approximation of ocean swell conditions, but more important because they form the building blocks from which it appears that the response to complex sea patterns can be constructed by calculation. These techniques are beginning to be applied, and model tests in irregular waves are now being used at Stevens to verify the theory. The studies must first be done in long-crested seas meeting the ship or model head on, but in time the work can be extended to different headings of the ship, to short-crested seas and finally to cross seas representing the superposition of a

storm sea and a swell, for example. For experimental work of this type, a square or rectangular tank is needed, with wavemakers along two sides.

A particularly important aspect of ship motions which can also be studied best by model experiment in a square tank is the interactions or couplings between the different motions—since they rarely if ever occur independently of one another. Pitch and heave coupling are considered in ordinary model tests in a straight tank. The most important other cases are yaw-heel and roll-pitch, which occur when the waves are not head-on.

These coupling effects have been dealt with quite thoroughly by Grim in Germany (Ref. 13). He has shown on the basis of both theory and experiment that if the periods of angular motion—pitch, roll and yaw—are multiples of one another, the effects are very pronounced. For example, a model having a pitching period ½ the rolling period was found to roll heavily in regular head seas. Professor Korvin-Kroukovsky of Stevens Institute of Technology returned from Europe in 1953 on a ship in which the rolling period was twice that of pitching, and the yawing period seemed be twice the rolling. Consequently, in quite moderate seas, the pitching built up appreciable rolling and yawing motion. Fortunately these coupling effects appear to be very sensitive to the period relationships and consequently can be avoided without too much trouble.

Thus our understanding of the ocean and of the motions of ships have greatly increased. Research has not yet revealed specific means of reducing pitching and heaving significantly and thus permitting higher speeds in bad weather, but it does suggest several lines of attack. Changing the ship's pitching period is a possible approach in the design stage, since it is strongly influenced by ship proportions, as well as by weight distribution. Another promising direction is to increase the damping of motion in order to reduce the amplitudes when resonance occurs or to apply vertical forces at bow and/or stern to cause the ship to follow the wave more closely—rising to the crests instead of diving into them. There are two possible ways of accomplishing these ends: (1) radical modifications of hull forms, perhaps in the direction of using more V-shaped sections, and (2) use of controlled retractible fins at one or both ends of the ship. Both of these ways will be explored in the near future at the Experimental Towing Tank at Stevens.

In conclusion, it may be said that we are undoubtedly on the verge of making real improvements in the sea speed of surface ships. This comes about as a result first of our better understanding of the characteristics of the sea surface. Much remains to be learned, but real advances have been made, particularly in basic theoretical aspects. Furthermore, both theoretical and experimental methods of dealing with ship speeds and motions in actual storm conditions have been developed to the point where various possible means of improvement can be evaluated. Hence, higher year-round speeds for surface ships can, it is believed, be confidently expected in the not too distant future.

Figures 2, 3, and 4 of this article, together with portions of the discussion of them, appeared originally in a paper by Professor B. V. Korvin-Kroukovsky and Edward V. Lewis, "Ship Motions in Regular and Irregular Seas," prepared for presentation at the Seventh International Towing Tank Conference, August 1954, published in Issue No. 6 (1955) of International Shipbuilding Progress, Rotterdam, Holland.

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KEY:

SNAME—Society of Naval Architects and Marine Engineers (New York)
INA—Institution of Naval Architects (London)
NEC Institution—North East Coast Institution of Engineers and Shpibuilders (Newcastle)

FACTORS INFLUENCING THE CONTINUING DEVELOPMENT OF THE STEAM TURBINE

ACKNOWLEDGEMENT

This is an abridged version of the Nineteenth Parsons Memorial Lecture presented before the Institution of Mechanical Engineers on 29 October 1954. Published in the November 1954 issue of *The Chartered Mechanical Engineer*, its author is F. Dollin, Chief Turbine Designer, C. A. Parsons and Company, Ltd.

EQUIPMENT USED FOR BLADING RESEARCH

Very early in his work on the steam turbine, Parsons, having introduced the principle of pressure compounding, satisfied himself that the best hydrodynamic efficiency was obtained with what is generally called 'reaction' blading but which, to be accurate, should be described as 50 per cent reaction. It was not Parsons' habit to disclose how he reached his conclusions, but it seems likely that in this instance he made experiments using water as the working fluid, and the correctness of his view as to the efficiency of 50 per cent reaction blading has never been seriously challenged.

In 1890, during the period when Parsons had temporarily lost control of his patents, he built an experimental turbine, which became known as 'Jumbo,' for radial-flow experiments. The following year saw the first use of separate blades and, as the art of manufacture developed, questions concerning shape and setting of blades demanded continuous attention and the need for a new and special experimental steam turbine became apparent.

Small Experimental Turbine. A small experimental turbine was designed for seven stages of axial-flow 50 per cent reaction blading. The diameter of the drum was at first 4½ inches, later increased to 6 inches and then to 8 inches, which became the standard. The exhaust pressure was atmospheric, the absolute pressure at inlet 1.15 atmospheres, the normal power output about 5 b.h.p. and the steam flow 1,600 lb. per hr. This machine, which was named 'Alice,' was thus a very small unit, really a laboratory piece of equipment, and it proved invaluable in use. It was characterized by a very low Mach number, as was 90 per cent of the blading used in the turbines that Parsons was building, and by a low Reynolds number, although these criteria were not explicitly used in connection with turbine blading at that time. The small size of 'Alice' enabled casings and rotors fitted with experimental blading to be produced comparatively quickly and economically, and the fact that it was a multi-stage turbine made it possible to include in the program tests on

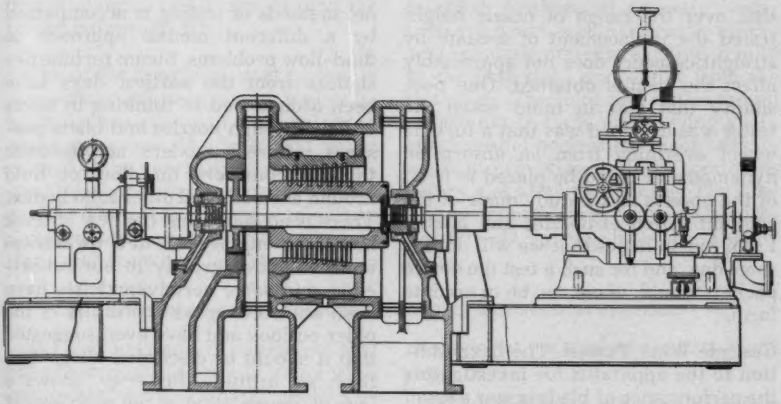


Figure 1. New Experimental Turbine

clearance effects, boundary forms and stage carry-over and carry-in. After a good many years' service 'Alice' showed signs of considerable wear and tear, and a new turbine, designed for the same blading dimensions but with improvements in detail, was built to carry on the work. The new turbine was named 'Alicia.' Besides being suitable for multi-stage reaction-blade test, it is equally adaptable for test on a single-impulse stage of diameter 15 inches and it has been much used in both capacities. It is still on the active list.

Static Nozzle Tester. Invaluable as 'Alicia' was, the need was felt for some other means of testing that would greatly reduce the time and cost of producing units to be tested, and would be suitable for investigations with working conditions of bigger pressure ratios and higher Reynolds number than those of 'Alicia.' The work that the Steam Nozzles Research Committee of the Institution carried on for a number of years had attracted much attention, and it was decided that a static nozzle tester would be a useful machine in a capacity supplementary to 'Alicia.' The nozzle tester that was designed and built in 1934 is quite different from that used by the Steam Nozzles Research Committee and more on the lines of one that was constructed in Germany by the A.E.G. The nozzles under test are suspended in such a way as to enable the reaction of the jet to be measured in both the axial and tangential directions, so that the mean efflux angle of the jets can be at once determined. The use of air instead of steam as the working fluid considerably simplified a number of problems, and the design and construction of the new tester benefited greatly from Parsons' interest in astronomical telescopes, inasmuch as the very sensitive, yet robust, suspension members were made in the neighboring optical works of Sir Howard Grubb, Parsons, on lines that had proved very successful in large wind-tunnel balances for aircraft research work.

In the early tests the blade or nozzle packets were of arcuate form concentric with the axis of the tester, but now straight packets are used, as they enable tests to be carried out on the effect of incidence and, at the same time, are simpler to make. Experience has shown

that over the range of nozzle height tested the replacement of arcuate by straight cascades does not appreciably affect the results obtained. One possibility that was in mind when the tester was designed was that a turbine wheel overhung from an absorption dynamometer could be placed in front of the nozzles and a study made of the conjoint action of nozzles and blades. I still live in hopes that we will do this some day, and for such a test the nozzle packets would, of course, be in arcuate form.

Cascade Wind Tunnel. The next addition to the apparatus for investigating the performance of blading was a small high-speed cascade wind tunnel which was built at the Royal Aircraft Establishment and was installed primarily for the study of compressor blading, but has been used also for work on turbine blading.

The wind-tunnel method of testing cascades is to measure the loss of energy of the fluid passing through the blades by traversing a total-head tube before and after the cascade, the tube being combined with some form of yaw meter which serves the dual purpose of measuring the efflux angle and yawing the total-head tube to the optimum direction. If the traversing is carried out carefully the total-head tube (that is, Pitot tube) can undoubtedly give good results. Whether the total-head tube is capable of recording accurately all the loss is perhaps a little doubtful since it records V^2 and can therefore respond to fluctuations in the velocity which it may not be intended or desirable to record. It can, however, be extremely useful in defining the region of low loss and it is probably true to say that, had such a method of testing compressor blades been available to Parsons, his efforts to develop the axial-flow compressor would have been greatly furthered.

The new approach to the study of blading losses provided by wind-tunnel methods of testing is accompanied by a different mental approach to fluid-flow problems. Steam turbine designers from the earliest days have been accustomed to thinking in terms of flow through nozzles and blade passages, whereas modern aerodynamic thought considers the flow of fluid around aerofoils and other solid bodies. There is no doubt that the new outlook has given engineers a new awareness and has added greatly to our knowledge, and some aerodynamicists have been known to speak scornfully of the older outlook and have even suggested that it should be discarded altogether. Such an attitude, however, shows a lack of appreciation of the problems of the turbine designer, who is concerned not only with flow patterns but also with mass flow and power output. The nozzle or blade-passage area is something that can be specified and measured and that determines the flow capacity of the turbine. In one sense the problem of turbine-blading design is simply the problem of fluid flow through orifices in series. It would seem, in fact, that, just as physicists use alternatively the wave theory of light and the quantum theory, so, in order to deal with all the flow problems involved, it is necessary sometimes to think of flow through a pipe or nozzle and sometimes of flow around an aerofoil.

New Experimental Turbine. Static methods of testing have proved of great value and are in constant use. At the same time they are no substitute for tests in a multi-stage turbine, which constitutes the final court of appeal. The latest addition to the blading research equipment under review is a seven-stage reaction turbine (Fig. 1) somewhat on the lines of 'Alicia' but larger. The spindle diameter is 13 inches and the normal speed of rotation 6,000 r.p.m. The ratio of inlet/exhaust pressure is 1.6/1 and, when exhausting at atmospheric pressure, the steam

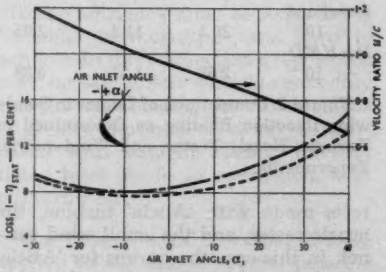
flow is about 21,000 lb. per hr. and the power output 280 b.h.p.

One of the most important factors in connection with accurate turbine testing is the measurement of the inlet and outlet pressures. The inlet and outlet casings of the new turbine were developed by means of air tests with wooden models. The objectives were to ensure a reasonably uniform flow to the first stage and from the last stage, and to establish positions of pressure measurement which would correctly represent the static pressure existing at inlet to the first stage and outlet from the last stage. The inlet and outlet annuli are similar in form, each having a circumferential perforated-sheet baffle to assist in providing uniform conditions before and after the blading. The final arrangement is largely due to suggestions made by the late Mr. Stanley Cook.

SOME INTERESTING RESULTS OBTAINED IN RESEARCH ON BLADING

The various items of equipment that have been described are in many ways supplementary and complementary to each other, and results obtained with one tester can sometimes be checked by suitably devised tests in another. An example of corroborative evidence of this kind is furnished by the comparison of losses in normal reaction blading as determined in turbine and nozzle tests. The loss as determined on the nozzle tester with various air-inlet angles ranging from minus 30 to plus 40 deg. is shown by the dotted line in Fig. 2, the ordinate scale being the loss expressed as a percentage of the available energy computed from the static pressure before and after the cascade. The broken line shows the corresponding curve derived from tests in 'Alicia' turbine over a range of velocity ratio equivalent to the same range of inlet angle, the relation between velocity ratio and inlet angle being shown by the upper curve. The agreement between the two loss-curves must be considered remarkably good both as regards shape and position, although there is a gradually increasing divergence as the positive inlet angle increases. The slightly smaller minimum loss found in the nozzle tester is probably accounted for by the higher Reynolds number. The flatness of the curves over a wide range of inlet angle, say from minus 30 to plus 15 deg., is characteristic of modern reaction blading.

It is not always found, however, that different experimental methods lead to concurrent results, and sometimes we are confronted with what H. G. Wells once called 'the rich confusion of reality.' Something of this kind is seen in Fig. 3 which shows the losses in semi-wing reaction blading as determined in

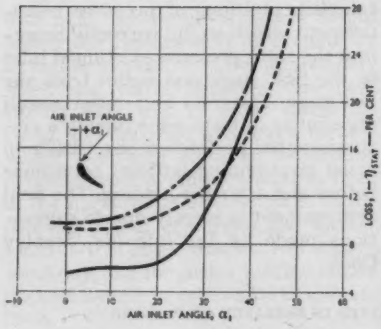


— — — — 'Alicia' turbine - - - Nozzle tester.

	Nozzle tester	'Alicia' turbine
Blade	640B	640B
Blade height, inch	0.875	0.875
Pressure ratio	1.10	1.01
O/P	0.37	0.35
P/c	0.592	0.598
Re-chord $\times 10^{-4}$	17.6	4.3
Re-HMD $\times 10^{-4}$	1.63	0.38

HMD-Hydraulic mean depth

Figure 2. Comparison of Losses in Normal Reaction Blading as Determined in Turbine and Nozzle Tests.



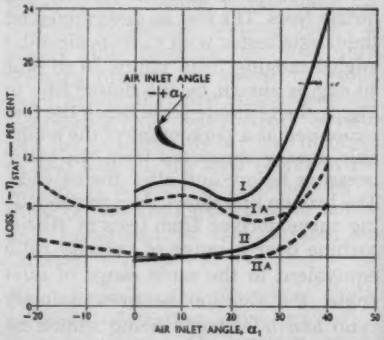
——·—— 'Alicia' turbine
— — — — Nozzle tester.
———— Wind tunnel.

	Nozzle tester	High-speed cascade tunnel	'Alicia' turbine
Blade profile	640B	630B	630B
Blade height, inch	0.875	1.0	0.875
Pressure ratio	1.10	1.10	1.01
O/P	0.499	0.50	0.484
P/c	0.65	0.66	0.62
Re-chord $\times 10^{-4}$	20.1	11.3	2.95
Re-HMD $\times 10^{-4}$	2.58	1.57	0.38

Figure 3. Comparison of Losses in Semi-wing Reaction Blading as Determined in Turbine, Nozzle Tester, and Wind-tunnel Experiments.

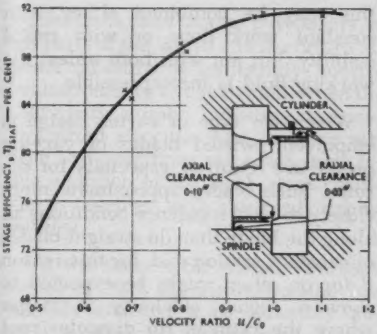
tests made with 'Alicia' turbine, the nozzle tester, and the small wind tunnel. In this case the curves for 'Alicia' and the nozzle tests are corroborative as to the value of the minimum loss, but not as to the best angle, and show a very material divergence with increasing positive inlet angle. The wind-tunnel curve must not be expected to agree with the others as it represents not the total loss, but only the profile loss measured at tthe mid-height of the blade. What is remarkable about it is the very steep rise when the positive angle exceeds 30 deg., the profile loss then exceeding the total loss as determined from the nozzle-tester results. This apparently anomalous result cannot easily be explained, but is not necessarily to be rejected as erroneous, as somewhat similar results have been found by other investigators in wind-tunnel tests on short blades. For three-dimensional tests on short blades the nozzle tester is considered more reliable than the wind tunnel.

The very searching nature of wind-tunnel tests is illustrated in Fig. 4 which again shows the losses for semi-wing blading in dependence on air-inlet angle. Curve 1 shows the results obtained with a cascade of blades 1-inch high in the small wind tunnel at a Mach number at outlet of 0.2. The hump occurring between zero angle and plus 20 deg. looked peculiar and improbable. This impression was strengthened when the tests were repeated at a Mach number of 0.6, for not only were the losses found to be much smaller (as expected) but there



Curve	I	IA	II	IIA
Blade profile	630B	630B	630B	630B
Blade height, inches	1	2	1	2
Tunnel	Small	Large	Small	Large
Re-chord $\times 10^{-4}$	5.83	6.14	19.06	19.47
Re-HMD $\times 10^{-4}$	0.82	0.93	2.68	2.93
Mach number	0.2	0.2	0.6	0.6

Figure 4—Wind-Tunnel Tests on Semi-wing Reaction Blading.



Stage efficiency with clearance loss plotted against velocity ratio.

Blade profile, 660B; mean blade height, 2.8 inches; axial clearance, 0.10; radial clearance, 0.03; *Re*-chord $\times 10^{-4}$, 13.7; *Re-HMD* $\times 10^{-4}$, 1.44.

Figure 5. Tests on Normal-reaction Blading in Large Experimental Turbine.

was no trace of a hump. A precisely similar cascade, except that the blade length was increased from 1 inch to 2 inches, was then made and tested at the same values of Mach number in a larger wind tunnel at another research establishment. The results of these tests are shown by the dotted lines and it is seen that they reproduce in a remarkable way the characteristics of the tests in the small tunnel. The fact that the losses are, in general, a little smaller is probably attributable to the bigger aspect ratio. The hump that occurs at the low Mach number (that is, low Reynolds number) is probably due to the flow in the boundary layer tending to become laminar.

As an example of the kind of information that can be obtained only from a multi-stage turbine, Fig. 5 shows the results of some tests made on normal reaction-blading in the large experimental turbine. The ordinate scale is the stage efficiency with clearance losses as run and the base scale is the adiabatic velocity ratio. The blading used is similar in all essentials to that employed commercially in currrent designs of high-pressure turbine. The fixed and moving blades carry shrouds which provide one axial and one radial seal in each case and a second radial seal at the outer surface of the spindle-blade shrouding is provided by a strip caulked into the cylinder. For the tests under consideration the axial clearances were 0.10 inch and the radials 0.03 inch, the mean blade height being 2.8 inches. With these clearances the peak efficiency obtained was just under 92 per cent. The fact that this form of blading is not dependent on the maintenance of very fine clearances for high efficiency gives the designer considerable freedom in the matter of turbine layout and arrangement.

The tests just described, when corrected to zero clearance, represent a blading efficiency approaching 95 per cent. This is in association with a not very high Reynolds number and an aspect ratio of about 2½/1, and it is evident that further improvements in blading efficiency must be expected to be small in magnitude and hard to achieve. In this connection a few words may be said about what is commonly called vortex blading, for which claims of greatly improved efficiency as compared with straight blading have at times been made in connexion with gas turbines.

The term 'vortex' is rather loosely applied to any one of several possible combinations of tangential- and axial-

Table 1. More Commonly-used Combinations of Tangential and Axial Flow

Axial flow	Tangential flow	
	Constant work done	Radial stability
Constant velocity	Case 1	Case 1
Constant mass velocity	Case 2	Case 3
Constant nozzle angle	Case 4	Case 5

flow conditions, the factor common to them all being the recognition of a radial pressure gradient in the annular space between the fixed and moving rows in each stage of any axial-flow turbine. The equation for the radial pressure gradient is

$$\frac{dp}{dr} = \frac{p}{g}\left[\frac{C_t^2}{r} - \frac{dC_r}{dt}\right]$$

where C_t and C_r are the tangential and radial components of fluid velocity at radius r. If it be assumed that 'cylindrical' flow exists, dC_r/dt is zero, and an explicit mathematical solution is then possible. In this context the more commonly used combinations of tangential and axial flow are shown in Table 1.

The conditions of constant work done at all radial distances from the center corresponds to the aerodynamic ideal of constant circulation round the blade. Radial stability denotes equilibrium between the centrifugal-force field and the radial-pressure gradient in the steam flow, and is considered in reference to the annular space between the fixed and moving blades.

The term 'free vortex' describes the combination of constant work done with constant axial velocity. This automatically fulfils the condition of radial stability but, with a compressible working fluid, involves some radial movement of the fluid outward in the stator blade-row and inward in the rotor blade-row. This latter condition is obviated if constant axial velocity is replaced by constant mass velocity, and this may be combined either with constant work done or with radial stability, but not with both unless the working fluid is incompressible.

Whichever type of vortex design is employed, twisted blades of varying profile are required, especially for the rotor. Such blades approximate more closely to ideal incidence conditions all along the blade than do straight blades of constant section and, for this reason if for no other, might be expected to show a higher efficiency in stages where the ratio of tip diameter/root diameter is relatively big.

The late Dr. Robert Dowson, who was in charge of blading research at Parsons' works for many years, gave a great deal of study to vortex theory and several sets of blades were made and tested in 'Alicia' turbine with a view to comparing the efficiency obtained with straight blades, blades twisted and flattened in accordance with the free vortex theory and also blades having a smaller degree of twist to give constant opening coefficient at all radii. For these tests the blades were made much longer than normal for 'Alicia,' the ratio tip diameter/root diameter being 2/1. These tests showed that the efficiencies of the several sets of blades were indistinguishable. This negative result does not stand alone, and it is to be inferred that fresh experimental evidence would be needed to justify the adoption of vortex type blading generally, instead of only in the low-pressure stages where it is at present employed.

STANDARDIZATION OF STEAM CONDITIONS AND TURBINE RATINGS IN GREAT BRITAIN

Turning now from hydrodynamics to thermodynamics, a salient factor in the period under review has been the standardization of steam conditions and turbine ratings. The time and labor that manufacturers have at times had to spend in working out designs and building plant to conform with an almost infinite variety of specified steam conditions and turbine ratings was a great handicap on production, and represented an enormous economic loss. This was fully realized before the 1939-45 war by manufacturers,

consultants, and many purchasers in all parts of the world and the desire for some measure of uniformity became widespread. In Great Britain, when the electricity-supply industry was nationalized after the war, the time was ripe and conditions were favorable for the adoption of standard steam conditions, together with standard turbine ratings.

At the time of Sir Charles Parsons' death in 1931 the steam turbine had already reached a considerably advanced stage of development. It was about this time that steam conditions of 600 lb. per sq. in. pressure and 800-850 deg. F. temperature were adopted for several new power stations for which a number of 30-MW. sets running at a speed of 3,000 r.p.m. were built. Machines of this rating to operate with these steam conditions were one of the two standards first specified by the newly created British Electricity Authority (B.E.A.) in 1947 and it seems appropriate therefore to take them as a datum for comparison.

A second standard laid down at the same time by the B.E.A. was for 60-MW. maximum and economical-rated machines for steam conditions of 900 lb. per sq. in. 900 deg. F. The concentration on these two standards was a wise policy and helped to make possible a big increase in the production of turbine-generators which were urgently needed as the first step towards relieving the acute shortage of such plant at the time.

Having launched a big program of these standard units the B.E.A. next placed orders for machines to operate with higher steam conditions, including 100-MW. units with steam conditions of 1,500 lb. per sq. in. 1,050 deg. F., others of the same rating for conditions of 1,500 lb. per sq. in. 975 deg. F. with reheating to 950 deg. F., and 120-MW. units for conditions of 1,500 lb. per sq. in. 1,000 deg. F. reheating to 1,000 deg. F. Hard on the heels of these there are now in the advanced design stage 200-MW. units for steam conditions of 2,350 lb. per sq. in. 1,050 deg. F. reheating to 1,000 deg. F.

When the first standards were laid down by the B.E.A. there was no stipulation as to vacuum, which did in fact vary considerably between different stations according to the cooling water available, 29.0 inches of mercury being a normal vacuum for stations with river-water cooling and 28.5 inches of mercury for stations dependent on cooling towers. However, as more and more stations go into commission there is a gradual increase in the average river-water temperature, while on the other hand the efficiency of cooling-towers has been materially improved and, in consequence, the difference in vacuum as between river stations and cooling-tower stations has narrowed. Average values today would be about 28.9 inches of mercury for river stations and 28.7 inches of mercury for cooling-tower stations.

EFFECT OF STEAM CONDITIONS ON EFFICIENCY AND OUTPUT

The question of the improvement in efficiency with higher steam conditions is one of primary importance, and has been the subject of several published papers and articles in the technical press. It is not proposed to deal with it at length here, but it is appropriate to look at the results obtained or expected from the various B.E.A. units already mentioned. The relevant figures are set out in Table 2.

It will be seen that the thermal efficiency of the 30-MW. turbine-generator, excluding all auxiliaries, is as high as 34.8 per cent. Each successive column shows an increase, the figure for the 200-MW. unit being 44.2 per cent.

TABLE 2. Thermal Efficiency and Other Data for Turbines Operating on Various Steam Cycles

	1	2	3	4	5	6
Stop valve pressure, lb. per sq. in. gauge	600	600	900	1,500	1,500	2,350
Stop valve temperature, deg. F.	850	850	900	1,050	1,000	1,050
Reheat temperature, deg. F.	—	850	—	—	1,000	1,000
Feed-water temperature, deg. F.	330	355	385	450	435	472
Stages of feed-heating	4	4	5	6	6	6
Economical rating, MW.	24	50	60	100	120	200
Maximum rating, MW.	30	50	60	100	120	200
Thermal efficiency excluding auxiliaries, per cent	34.8	36.7	37.4	40.4	41.6	44.2
Deduction for turbine auxiliaries*, per cent	2.1	1.85	2.4	2.75	2.5	2.9
Corrected thermal efficiency, per cent	34.07	36.02	36.5	39.3	40.56	42.9
Relative fuel consumption	104	94.5	93.3	86.7	84.0	79.3
Steam rate to turbine, lb. per kW.-hr.	8.4	7.51	8.36	7.59	6.69	6.35
Steam rate to condenser, lb. per kW.-hr.	6.72	5.80	6.12	5.31	4.76	4.32
Relative output for constant last row annulus and constant per cents leaving loss	100	129	112	147	182	198

The necessary allowances for the auxiliary power and steam requirements depend on a great many factors and are liable to some variation, but the figures given in Table 2 are reasonable estimates on a comparable footing for the various units. As between a reheat and non-reheat machine for the same initial pressure and temperature, there in an appreciable reduction in auxiliary power for the reheat machine on account of the considerably lower steam consumption which is reflected in the boiler feed-pump power.

Table 2 shows the values of thermal efficiency corrected for auxiliary requirements, and also the corresponding values of relative fuel consumption, taking that for the 30-MW. unit as being 100.

omparing column 2 with column 1, it is seen that with the same initial conditions of 600 lb. per sq. in. 850 deg. F., intermediate resuperheating to 850 deg. F. shows a saving in fuel consumption of 5.5 per cent. Some proportion of this gain is due to the bigger rating of the reheat machine, the net gain directly attributable to reheating being about 5 per cent.

Comparing columns 3 and 1, it is seen that for the 60-MW. units operating with steam conditions of 900 lb. per sq. in. 900 deg. F. there is a fuel saving of 6.7 per cent as compared with the 30-MW. units. About 1 per cent of this is due to the higher efficiency of the generator, the 60-MW. unit being hydrogen cooled and the 30-MW. air cooled.

It will perhaps cause some surprise on looking at column 4 to see that the step from 900 lb. per sq. in. 900 deg. F. to 1,500 lb. per sq. in. 1,050 deg. F. achieves no greater saving in fuel consumption than the step from 600 lb. per sq. in. 850 deg. F. to 900 lb. per sq. in. 900 deg. F. This is an illustration of the increasing difficulty attendant upon each successive advance.

For the 120-MW. unit the saving in fuel consumption as compared with the 30-MW. unit is 16 per cent, and for the 200-MW. unit the saving exceeds 20 per cent.

The effects of increased pressure and temperature on the maximum output obtainable are perhaps more striking than their effects on thermal efficiency. With higher steam conditions, the energy available by adiabatic expansion is increased and the steam rate to the turbine correspondingly reduced. At the same time a greater proportion of the steam is bled to produce a higher feed-water temperature and, in consequence, the steam rate to the condenser is further reduced. Therefore, for a given last-row blade-annulus area and steam-exit velocity, the power output increases markedly with increase of initial pressure and temperature. Furthermore, in view of the increased available energy with the high conditions, a given steam-exit velocity represents a smaller percentage leaving loss, and for equal percentage leaving loss the output obtained with increased steam conditions is still further enhanced. The relative figures computed on this basis are shown in Table 2, the output for the 600 lb. per sq. in. 850 deg. F. steam conditions being taken as 100.

On comparing column 2 with column 1, it is seen that the adoption of reheating, while retaining the same initial pressure and temperature, enables 29 per cent more power to be obtained with a given exhaust area for the same percentage leaving loss. A very similar result is found from comparison of columns 5 and 4, bearing in mind that in this case the comparison is a little affected by a difference in the stop-valve temperature. These comparisons bring out the important effect of reheating on the output factor, and it is evident that when units of the maximum possible output are required, reheating must always be employed. It will be seen that with steam conditions of 2,350 lb. per sq. in. 1,050 deg. F. reheating to 1,000 deg. F., the relative output as compared with 600 lb. 850 deg. F. is practically doubled.

In connection with the question of the effect of steam pressure and temperature on the cycle efficiency it may be remarked that technical development has again run ahead of scientific knowledge relating to the properties of steam. A temperature of 1,050 deg. F. is already accepted for large steam turbines and still higher temperatures are in prospect. The Callendar steam tables at present in use do not extend beyond 1,000 deg. F. The Keenan and Keyes tables extend to 1,600 deg. F., but are based on extrapolation of experimental data at temperatures not exceeding 860 deg. F. and do not coincide with the Callendar data at the upper end of the chart. Some new steam tables have recently been issued in Russia based, it is understood, on experiments at temperatures up to 1,112 deg. F. but not in conjunction with very high pressures.

In comparing cycle efficiencies, using different steam tables, it is possible to obtain results differing by several tenths of one per cent. The importance of this may be appreciated when it is realized that the capitalized value of one tenth of one per cent on the consumption of 120-MW. unit is over £5,000. The British electrical industry has for long been very much alive to this and, in 1946, allocated funds in support of new researches on the thermodynamical properties of steam in the field of high pressure and temperature. Apparatus for the very exact measurement of the total heat of steam at pressures up to 6,000 lb. per sq. in. and temperatures up to 1,400 deg. F. has been designed and built and calibrated at the Imperial College of Science and Technology under the direction of Professor D. M. Newitt, F.R.S. The obtaining and formulating of data that will enable a new steam table and chart to be issued, extending up to at least 1,200 deg. F. as a first stage, is a matter of urgent importance.

A new factor in the power situation

is the advent of the atomic pile, which turns attention in a different direction from the trend towards higher pressures and temperatures that we have been reviewing. Sir Christopher Hinton has stated that although there is no nuclear-physical reason why the fission process should not be operated at a very high temperature there are compelling engineering and metallurgical reasons for not attempting to do so at the present time. For the gas-cooled natural uranium reactor he gives 350 deg. C. (662 deg. F.) as the approximate temperature of coolant leaving the reactor, which limits the temperature of the working fluid for the prime mover to about 600 deg. F. The design problems associated with steam turbines for atomic power plant are therefore at the opposite end of the scale from those associated with modern coal-fired plant, and arise from the relatively small available energy, the big volumetric flow in relation to the power output and the use of steam with a higher moisture content than normal. Atomic power plant is at present only in the embryonic stage and its potentialities offer a fascinating and unpredictable field of development.

TRENDS IN TURBINE DESIGN

For power generation at 50-cycle frequency the maximum possible rotational speed of 3,000 r.p.m. for direct-coupled machines is now almost universal. Therefore, to obtain increased area at the exhaust end corresponding to an increase in power output, it is necessary either to go to higher blade-tip speeds or more exhausts or both. Turbines are now running in Britain with a last-row blade-tip speed of about 1,250 ft. per sec., equal to the acoustic velocity for the steam entering the condenser. Considerably higher speeds are found in many turbines in the United States, where the electrical frequency is 60 cycles per sec. and the rotational speed 3,600 r.p.m., and the present limit for 3,000 r.p.m. units will be surpassed in a number of large turbines at present under construction or being designed in Britain.

These high-speed last-row blades are one of the major problems in turbine design. The blade length is approximately half the rotor diameter and the ratio tip area/root area approximately 1/7, a taper-parallel or 'lighthouse' taper being employed to keep the stress within acceptable limits. The blades are designed in accordance with one or other of the vortex theories, and this automatically results in a blade profile that is deeply cambered at the root and flat at the tip, which is advantageous in respect of blade strength and relatively-high natural frequency of vibration.

With the higher blade speeds now in vogue, it is in some cases possible to use fewer exhausts than has hitherto been the practice for certain ratings. For instance, the standard design of a 30-MW. set has been a two-cylinder turbine with a double-flow low-pressure casing. A single-cylinder single-exhaust turbine of this rating is now feasible.

The desire for compactness may also lead to a reduction in the number of casings even although the number of exhausts remains the same. As an example of this, a new design of 60-MW. unit employs two cylinders and two exhausts in comparison with a three-cylinder two-exhaust machine of the same rating and for the same steam conditions. The latter is an all-reaction machine, the high-pressure casing having the clamped type of horizontal joint. The two-cylinder design has a velocity wheel for the initial stage with reaction blading in all other stages.

The 100- and 120-MW. reheat machines now under construction by Parsons for the B.E.A. have three cylinders and three exhausts, two in the double-flow low-pressure cylinder and one in the intermediate-pressure cylinder, and a brief description of these machines may be of interest. At full load the steam expands in the high-pressure turbine from 1,425 to 400 lb. per sq. in. gauge, passing thence to the reheater. The reheated steam enters the intermediate-pressure turbine at a pressure of 360 lb. per sq. in. gauge and, at a stage where the pressure is 20 lb. per sq. in. gauge, the flow is divided, one portion going straight on through further blade rows to the intermediate-pressure exhaust while the remainder is led away through two overhead interconnecting pipes to the low-pressure turbine inlet.

The high-pressure turbine is of the impulse-reaction type and a double cylinder casing is employed. There are no partial load valves and the impulse stage operates with the maximum arc of admission at all times. The arc of admission is interrupted only at the ends of the nozzle ports, which are closed off so that the horizontal joint of the inner cylinder is subjected only to reaction stage pressure and not to the full inlet pressure. Each of the four high-pressure steam pipes is bolted to the outer casing by means of a flange that is welded to a petticoat which, in turn, is welded to the pipe. The pipe extends radially inwards beyond the petticoat and passes through a gland in the inner casing to the nozzle chamber.

The intermediate-pressure cylinder is a single shell and has a flanged and bolted horizontal joint of the conventional type. There is no velocity wheel in the intermediate-pressure cylinder, and the reheated steam is fed symmetrically into the casing by two pipes in the top half and two in the bottom half.

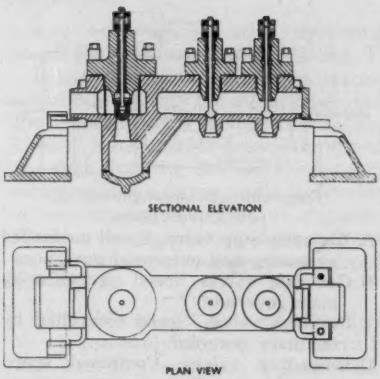
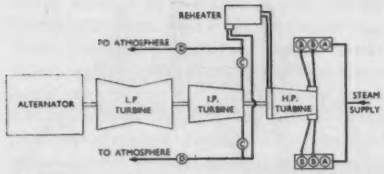


Figure 6. Forged High-Pressure Steam Chest.

The low-pressure turbine itself calls for no particular comment, the provision of three exhausts enabling a fully adequate total blade annulus area to be obtained without involving abnormally high blade-tip speeds. With three exhausts the question of what is the best condenser arrangement to adopt becomes a problem because of the increased span required to accommodate three exhausts in line. For the 100-MW. sets a single condenser has been adopted, with two unequal steam inlet branches but with the tube nest offset to improve steam distribution. For the 120-MW. sets two-condensers are employed, one of two-thirds and one of one-third capacity. With the latter arrangement, a center column is provided between the condensers, thus reducing the unsupported span of the longitudinal beams.

A forged construction has been adopted for the two high-pressure steam chests, each of which contains one runaway stop-valve and two governor valves (Fig. 6). All the valves are of the single-seated high-velocity type with diffusers, the four governor valves opening and closing together. The steam-chest relays on these ma-



Diagrammatic arrangement of protective valves.

A Runaway stop valve. Speed controlled by emergency overspeed governor.
B Governor valves. Speed controlled by main governor.
C Intercept valves. Speed controlled by auxiliary governor.
D Unloading valves. Combined speed control by auxiliary governor and reheat pressure control.

Figure 7. 100,000-kW. Continuous Maximum Rating Reheat Turbo-alternator.

chines are arranged at the side and the valves are operated through lever linkage.

If a reheat turbine carrying full load should become disconnected from the electrical supply system, the steam stored in the reheater and connecting piping would produce an unduly high temporary speed rise after the valves admitting steam to the high-pressure turbine had closed under the action of the control system, unless special means were provided to prevent this happening. There are various ways of achieving this end; the provision made on the machines here described being shown in Fig. 7. The reheated steam is conveyed by two pipes to two intercept valves and thence to the intermediate-pressure turbine. Some distance upstream of the intercept valves there is on each steam pipe an offset chamber housing a single-seated unloading valve which is closed under all normal operating conditions, while the intercept valves are normally open. Both the intercept and unloading valves are relay-controlled by an auxiliary governor mounted at the steam end of the high-pressure turbine. The unloading valves also serve to act as relief valves on the reheater system if the steam admission valves on the high-pressure turbine should fail to close completely.

In the general outlook, a very important factor affecting power-plant design is the greatly improved reliability of steam boilers so that the boiler availability is now comparable to that of the turbine. Arising out of this, a logical development is the arrangement of one boiler connected to one turbine as a single unit, all cross connections between boilers being eliminated. This enables great simplification of the plant layout in respect of piping, valves, etc., to be achieved. Also, it virtually makes each unit an independent power station and so gives freedom to adopt different steam conditions for later machines in the same station, if desired, without reference to the conditions for existing machines. The arrangement of one boiler supplying one turbine does not directly affect the general design of the turbine, but it does require certain safeguards and affects the starting technique for intermittent operation. When a unit boiler is banked overnight the temperature of the steam available for starting the unit next morning is liable to be appreciably lower than that of the turbine casing, steam chest, etc. It is very undesirable to admit cool steam to a hot turbine, and special provision in the way of superheater controls and blow-off connections (sometimes involving a dump condenser) are necessary to bring the temperature of the steam up to that of the turbine casing. Another factor is that if for any reason the boiler pressure should start to fall, the turbine governor valves will open wider and the water-level in the boiler may fall to a dangerous extent. To obviate this danger, it is the practice to fit an automatic control which, in the event of the boiler pressure falling below a predetermined figure, will start to close the governor valves and unload the turbine.

MATERIALS OF CONSTRUCTION

When dealing with ferrous metals at temperatures not exceeding, say, 800 deg. F., their mechanical properties need be considered only in terms of the relation between stress on the one hand and deformation and fracture on the other. In the high-temperature region, however, the effect of an applied stress depends on the temperature and also on the time for which it is applied, and the mechanical properties of the metal therefore have to be considered in terms of the relations between stress, temperature and time on the one hand and deformation and fracture on the other.

Steam-turbine rotors and casings and other main parts normally work under conditions of approximately constant stress. A criterion that is commonly used in the design of such components for high-temperature steam turbines is that under the working stress/temperature conditions the material should not extend by more than 0.1 per cent in 100,000 hours, a period equivalent to eleven years' continuous operation. It is also necessary that the working stress should be well below the stress-to-rupture in the same period. Sometimes a factor of safety of 2 on the rupture stress is employed, and this not infrequently gives a working stress about equal to, or rather less than, that corresponding to 0.1 per cent creep in 100,000 hours. These criteria together are considered to provide a safe and conservative basis for design, and may not always give the highest permissible stress.

Plain carbon steel has been employed successfully for forged rotors, cast cylinders and steam chests with operating temperatures up to 800 deg. F. For the same components in turbines operating with steam at 850 deg. F. carbon steel with the addition of 0.5 per cent molybdenum can be regarded as standard, and this material has proved satisfactory for turbine rotors and casings with operating steam temperatures up to 925 deg. F.

It has also been in extensive use for a number of years for steam pipes, but the bursting of a steam pipe in the United States in 1943 drew attention to the fact that the heat-affected zones adjacent to welds are liable to develop serious weakness as a result of graphitization during prolonged exposure to temperatures extending upwards from 850 deg. F.

The addition of 1 per cent chromium to carbon-molybdenum steel greatly increases the resistance to graphitization and also improves the creep properties to some extent. This steel has therefore superseded carbon-molybdenum steel for pipes.

The resistance to creep of carbon-molybdenum and chromium-molybdenum steels falls off rapidly as the temperature approaches 1,000 deg. F., and for this field we turn to the group of ferritic steels containing molybdenum and vanadium, the high-temperature mechanical properties of which depend on the heat treatment they have received. The original molybdenum-vanadium steel contained 0.5 per cent molybdenum and 0.3 per cent vanadium with a carbon content of 0.12 per cent and no chromium. From this a number of chromium-molybdenum-vanadium steels have been developed containing various combinations of chromium up to 3 per cent, molybdenum up to 1 per cent and vanadium up to 0.8 per cent.

Fig. 8 shows the stress-temperature relation for 0.1 per cent creep in 100,000 hours plotted against temperature for carbon, carbon-molybdenum, chromium-molybdenum, and molybdenum-vanadium steels. Subject to possible modification as experience grows, it seems probable that molybdenum-vanadium or chromium-molybdenum-vanadium steel should have

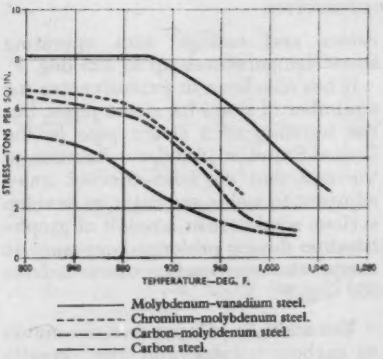


Figure 8. Stress-Temperature Relation for 0.10 per cent Creep in 100,000 hours.

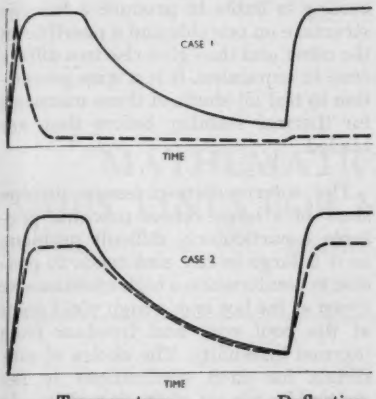
adequate strength for the main components of steam turbines working at temperatures up to 1,050 deg. F.

Bolt steels are required to have a high yield point at room temperature as well as good creep properties, and for this reason they sometimes have a high carbon content and are used in the quenched and tempered condition. For many years the normal bolt material was a chromium-molybdenum steel containing 0.6 per cent molybdenum, 1.4 per cent chromium, and 0.4 per cent carbon and this has proved satisfactory in service on turbines operating at temperatures up to 925 deg. F., the bolts themselves being some 50-100 deg. F. lower in temperature. Chromium - molybdenum - vanadium bolt steels have now been introduced, the best of which seem to be some 100-150 deg. F. better than chromium-molybdenum steel for the same creep rate at a given stress.

Bolts are generally subjected in service not to constant stress, but to constant total strain. In the course of time, as the material creeps, the elastic strain (and therefore the stress in the bolt) diminishes. This is not disastrous but, sooner or later, the tension in the bolts diminishes so far that retightening of the bolts becomes essential to prevent leakage at the joint.

For blading, 13 per cent chromium stainless iron or steel has for long been the standard material of nearly all turbine manufacturers. Its creep resistance is about the same as that of plain carbon steel but, as the direct stress in the blades at the high-pressure end of a turbine is not usually very high, stainless iron has proved quite satisfactory in steam turbines at 925 deg. F. For higher temperatures, blading material with better creep properties is needed to ease the problems of design, and a stainless iron containing 0.8 per cent molybdenum has been introduced. This has a creep resistance similar to carbon-molybdenum steel and can probably be used up to about 1,000 deg. F. Much work is being done on the development of more complex steels in this group, and there is every prospect that the field of application of stainless ferritic steels will be considerably extended.

The temperatures employed with modern steam turbines have now risen to a point where it is necessary that the materials should have not only suitable mechanical properties, but also satisfactory oxidation resistance under the working conditions. The high-temperature mechanical properties of carbon-molybdenum and chromium-molybdenum steels restrict their use to temperatures at which their resistance to oxidization is fully adequate. The molybdenum-vanadium and chromium - molybdenum - vanadium steels have much better high-temperature mechanical properties, but not better resistance to oxidation, and it is important to know whether the upper limit of temperature for which these steels are suitable is determined by creep properties or oxidation resistance. From the point of view of oxidation resistance it can be said that all these low-alloy steels become



——— Temperature. — — — Deflection.

Figure 9. Thermal Instability of Rotors.

unsuitable for use at temperatures above about 1,050 deg. F.

When steels are required to withstand stress and oxidation for long times at temperatures above 1,050 deg. F., it is generally considered necessary at the present time to use austenitic steel of the 18 per cent chromium, 12 per cent nickel, and 1 per cent niobium type. There are, however, serious objections to the use of austenitic steels. They are expensive, difficult to cast and forge, and not easy to machine. They have a low yield point at room temperature, a high coefficient of expansion which gives rise to big movements or forces and makes the control of clearances difficult, and a low thermal conductivity which, in conjunction with the high coefficient of expansion, gives rise to high thermal stresses. Because of these difficulties much attention is now being given to the development of 6 and 12 per cent chromium ferritic steels alloyed with such elements as titanium, vanadium, and niobium to give high creep-resistance. It is hoped that in this way the temperature at which it becomes necessary to use austenitic steels can be raised to 1,150 deg. F.

A topic that has received considerable attention in recent years is the thermal instability of rotors. Assuming that the forging is received by the turbine builder from the steel-works in the normalized condition, it should be free from internal stresses, and there are then two kinds of instability that may occur, the characteristic features of which are illustrated in Fig. 9. In the first case, when the shaft is heated while rotating slowly it starts to bow and shows an increasing deflection with increase of temperature up to a certain point, beyond which the deflection diminishes until the shaft is nearly straight. It remains in this condition while cooling down and shows no repetition of the initial high deflection when heated up a second time. This 'once only' deflection is presumably due to some surface effect resulting from the machining of the shaft, and it can be taken care of by slowly rotating and heating the shaft before it is bladed.

In the second case, the shaft develops a bend increasing in proportion as the temperature is raised, straightening out during cooling down and showing precisely the same bend when heated a second time. This kind of shaft is not usable and cannot be cured by anything the turbine builder can do. At our works this phenomenon has not been encountered with carbon-steel shafts but it has occurred occasionally with carbon-molybdenum steel shafts and has been very fully investigated in conjunction with the steel makers. It has now been established that the difficulty arises from non-uniformity of structure in the forging. Coefficient of expansion determinations carried out on specimens cut from each side of the shaft showed the coefficient on the convex side to be slightly greater than on the concave. Although the difference is only 1 or 2 per cent it is sufficient to produce a shaft deflection at steam temperature of the order of 0.01

inch, which is more than sufficient to throw the shaft so far out of balance that it cannot be run.

A detailed account of the investigation of the thermal instability of turbine shafts by A. Barker and F. W. Jones of the Brown-Firth Research Laboratories will shortly be published. Their work has shown that the difference in coefficient of expansion between one side of a shaft and the other arises from the development, during normalizing, of a bainitic structure on one side of the shaft and a pearlitic structure on the other. This structural difference arises in turn from some difference in the heating temperature or rate of cooling between one side of the shaft and the other. The composition of the steel used has an important influence in this connection. Thus with carbon steel shafts it is possible to have substantial differences in the heating temperature or rate of cooling on opposite sides of a shaft and still get a pearlitic structure all round, and, again, with shafts containing a sufficient amount of alloying elements it is possible under similar conditions to get a bainitic structure all round. It is in shafts made of carbon-molybdenum and molybdenum-vanadium steels that slightly unsymmetrical heating or cooling is liable to produce a bainitic structure on one side and a pearlitic on the other and thus give rise to a difference in expansion. It is a wise precaution to test all shafts of these materials for thermal stability before they are bladed.

The intermediate-pressure turbine shaft of a large reheat machine presents a particularly difficult problem, as it is large in size and needs to possess in combination a high resistance to creep at the hot end, a high yield point at the cool end, and freedom from thermal instability. The choice of materials for such applications is restricted by reason of the fact that only a few steels are known to have sufficiently good creep properties, and their compositions are not the most suitable for giving a high yield point and ensuring thermal stability in large shafts. In these circumstnaces a satisfactory solution of the problems involved may be assisted by resorting to oil hardening instead of normalizing, since this makes it easier to obtain a high yield point in the body of the material at the cold end and also increases the creep resistance at the hot end. As a safeguard against thermal instability, vertical heat-treatment associated with rotation is important.

MATHEMATICAL FAIRING OF SHIPS' LINES FOR MOLD LOFT LAYOUT

ROBERT TAGGART

THE AUTHOR

received his Bachelor of Science degree in Naval Architecture and Marine Engineering from Webb Institute of Naval Architecture in 1942. He was employed as a mold loftsman by the Consolidated Steel Corporation and has done preliminary design work with the U. S. Maritime Commission and the U. S. Army Transportation Corps. He was in charge of the Noise Section, Applied Science Division, of the Bureau of Ships, and is presently Chief, Analytical Engineering Department, Reed Research, Inc.

INTRODUCTION

The concept of mathematical representation of ships' lines was probably first brought out in this country by Admiral D. W. Taylor in his famous paper delivered before the International Engineering Congress in San Francisco in 1915. Although he envisioned, as have many others, the establishment of a mathematical relationship between ship form and wave making resistance, he had another fundamental reason for the adaptation of mathematical curves to ships' lines. He desired to run a series of model resistance tests of a ship form with a systematic variation of certain basic form parameters. Therefore he modified somewhat the lines of the armoured cruiser, HMS *Leviathan*, and fitted to them a series of mathematical waterlines and station lines based upon those parameters he wished to vary. This resulted in Experimental Model Basin Model 632.

The waterlines were separated fore and aft, and a fifth order curve of the form $y = a + bx + cx^2 + dx^3 + ex^4 + fx^5$ was fitted to each half of each waterline. The y value was the ordinate, or half-breadth, and the x value was the abscissa, or station spacing. Before fitting the mathematical curve he reduced each waterline to nondimensional form; i.e., the ordinates of each point were divided by the maximum half-beam of the waterline and the abscissas of each point were divided by the entrance length of the ship. This reduced the curve to the form show in Fig. 1.

Admiral Taylor had chosen a curve which passed through the points $(x = 0, y = 0)$ and $(x = 1, y = 1)$. Thus, part of the solution for the mathematical curve was obtained for:

when $x = 0, y = a = 0$ *and*
when $x = 1, y = a + b + c + d + e + f = 1$

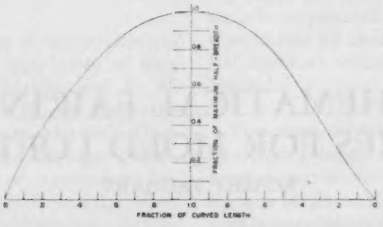


Figure 1. EMB Model 632 load waterline.

He further defined the slope at the bow as t and prescribed that the slope at the point $(x = 1, y = 1)$ should be zero or:

$$\text{when } x = 0, \frac{dy}{dx} = b = t \text{ and}$$

$$\text{when } x = 1, \frac{dy}{dx} = b + 2c + 3d + 4e + 5f = 0$$

In addition, Admiral Taylor utilized the second derivative of the curve which he called the acceleration, α. This was determined at the point $(x = 1, y = 1)$ and resulted in the equation:

$$\text{when } x = 1, \frac{d^2y}{dx^2} = 2c + 6d + 12e + 20f = \alpha_1$$

In order to include the area of the curve, or the waterline coefficient, he integrated the curve and equated the resulting area to the coefficient p or:

$$\int_{x=0}^{x=1} y dx = \left[ax + \frac{bx^2}{2} + \frac{cx^3}{3} + \frac{dx^4}{4} + \frac{ex^5}{5} + \frac{fx^6}{6} \right]_{x=0}^{x=1}$$

$$= a + \frac{b}{2} + \frac{c}{3} + \frac{d}{4} + \frac{e}{5} + \frac{f}{6} = p$$

He thus ended up with six equations and six unknowns:

$$a = 0$$
$$b = t$$
$$a + .b. + c + d + e + f = 1$$
$$b + 2c + 3d + 4e + 5f = 0$$
$$2c + 6d + 12e + 20f = \alpha_1$$
$$a + \frac{b}{2} + \frac{c}{3} + \frac{d}{4} + \frac{e}{5} + \frac{f}{6} = p$$

These equations could be solved in terms of the measurable quantities t,p and α_1. Thus, a mathematical curve could be fitted to a known waterline curve.

Admiral Taylor carried this principle further to fit fourth degree parabolas and hyperbolas to the section curves. By systematic variation of the prismatic coefficient, displacement-length ratio, and beam-draft ratio he produced a series of mathematical forms which were constructed, and tested, and which resulted in the well-known Taylor's Standard Series.

BACKGROUND

Early in 1950 the Hydrodynamics Committee of the Society of Naval Architects and Marine Engineers decided to attempt to utilize its Model Resistance Data Sheets to establish a relationship between various hull form parameters and model resistance. One phase of this program involved the determination of waterline curvature along the length of the ship. Curvature is defined as the reciprocal of the radius of curvature. In other words, if at each point along a waterline a circular arc were drawn which contained the waterline at that point, the curvature would be the reciprocal of the radius of that circular arc. The curvature of a straight line is zero. The curvature of a right angle is infinite. Mathematically the curvature is:

$$K = \frac{y''}{[1 + (y')^2]^{3/2}}$$

The first approach to obtaining curvature was by the method of first and second differences of ordinates to obtain functions of the first and second derivatives. It was immediately obvious that waterline plots which were roughly accurate to three significant figures were entirely too inaccurate for this approach. Next a series of circular arcs of systematically increasing radii were reproduced on a film positive. The arcs on this film were fitted to points along typical waterline curves and the curvature computed. This was a much more successful method but it showed many inconsistencies. These inconsistencies were traced back to the waterline curves themselves. Even when large scale plots were made from mold loft offsets these inconsistencies existed. The one conclusion which could be drawn was that the waterline curves *were not fair!*

The next step was to develop mathematically faired curves which represented, in all basic characteristics, the original lines. The first approach utilized the methods developed by Admiral Taylor. It was soon found, however, that (1) the slope and acceleration of the waterline curve could not be determined with sufficient accuracy to closely reproduce the original waterline curve. It was also found (2) that the fifth order curve, while perfectly satisfactory for EMB Model 632, could not follow the extremely full afterbody waterlines in some ships or the abrupt changes in forebody curvature of others.

To overcome the first problem it was decided to use integrated relationships instead of differentiated relationships to determine the unknowns involved. The relationships which appeared the most satisfactory were the area, moment of area, square moment of area, and cube moment of area. It was found that by extending Taylor's concept to a sixth order curve, a mathematical curve could be obtained which fitted the waterlines of all vessels of normal form. Mathematically the nondimensional curve was then expressed as:

$$y = ax + bx^2 + cx^3 + dx^4 + ex^5 + fx^6$$

Since the curve is assumed to pass through the point $(x = 0, y = 0)$ the con-

stant term has been eliminated. Taylor's qualification that the curve pass through the point $(x = 1,\ y = 1)$ has been retained, or:

$$a + b + c + d + e + f = 1$$

and that the slope at this point is zero, or:

$$a + 2b + 3c + 4d + 5e + 6f = 0$$

To solve for the remaining unknowns, the following constants were selected:

C_1 = function of area
C_2 = function of moment of area
C_3 = function of square moment of rea
C_4 = function of cube moment of area

or expressed mathematically:

$$C_1 = \int_{x=0}^{x=1} y\,dx = \int_{x=0}^{x=1} (ax + bx^2 + cx^3 + dx^4 + ex^5 + fx^6)\,dx$$

$$C_2 = \int_{x=0}^{x=1} xy\,dx = \int_{x=0}^{x=1} (ax^2 + bx^3 + cx^4 + dx^5 + ex^6 + fx^7)\,dx$$

$$C_3 = \int_{x=0}^{x=1} x^2y\,dx = \int_{x=0}^{x=1} (ax^3 + bx^4 + cx^5 + dx^6 + ex^7 + fx^8)\,dx$$

$$C_4 = \int_{x=0}^{x=1} x^3y\,dx = \int_{x=0}^{x=1} (ax^4 + bx^5 + cx^6 + dx^7 + ex^8 + fx^9)\,dx$$

For any waterline curve we can solve for the unknowns a, b, c, d, e, and f in term of the constants C_1, C_2, C_3, and C_4. This procedure is mathematically simple, but to the computer extremely tedious. The results are:

$$a = 30 + 420\,C_1 - 3360\,C_2 + 7560\,C_3 - 5040\,C_4$$
$$b = -435 - 4200\,C_1 + 37{,}800\,C_2 - 90{,}720\,C_3 + 63{,}000\,C_4$$
$$c = 1960 + 14{,}700\,C_1 - 141{,}120\,C_2 + 352{,}800\,C_3 - 252{,}000\,C_4$$
$$d = -3780 - 23{,}520\,C_1 + 235{,}200\,C_2 - 604{,}800\,C_3 + 441{,}000\,C_4$$
$$e = 3276 + 17{,}640\,C_1 - 181{,}440\,C_2 + 476{,}280\,C_3 - 352{,}800\,C_4$$
$$f = -1050 - 5040\,C_1 + 52{,}920\,C_2 - 141{,}120\,C_3 + 105{,}840\,C_4$$

To apply this to a specific waterline, the constants C_1, C_2, C_3, and C_4 must be determined. It has been found satisfactory to reduce the waterline to non-dimensional form and to divide it into ten equally spaced stations. The constants are computed using Simpson's First Rule in the manner normally used for computing area, moment, and moment of inertia, or:

$$C_1 = \Sigma_0^1\, y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + 4y_5 + 2y_6 + 4y_7 + 2y_8 + 4y_9 + y_{10}$$

$$C_2 = \Sigma_0^1\, x_0y_0 + 4x_1y_1 + 2x_2y_2 + 4x_3y_3 + 2x_4y_4 + 4x_5y_5 + 2x_6y_6 + 4x_7y_7 + 2x_8y_8 + 4x_9y_9 + x_{10}y_{10}$$

$$C_3 = \Sigma_0^1\, x_0^2y_0 + 4x_1^2y_1 + 2x_2^2y_2 + 4x_3^2y_3 + 2x_4^2y_4 + 4x_5^2y_5 + 2x_6^2y_6 + 4x_7^2y_7 + 2x_8^2y_8 + 4x_9^2y_9 + x_{10}^2y_{10}$$

$$C_4 = \Sigma_0^1\, x_0^3y_0 + 4x_1^3y_1 + 2x_2^3y_2 + 4x_3^3y_3 + 2x_4^3y_4 + 4x_5^3y_5 + 2x_6^3y_6 + 4x_7^3y_7 + 2x_8^3y_8 + 4x_9^3y_9 + x_{10}^3y_{10}$$

CURVE 22.50 FOOT WATERLINE - FOREBODY

x	ORD.	M_1	M_2	M_3	M_4
0	0				
.1	.124	2	1	1	1
.2	.287	1	1	2	4
.3	.443	2	3	9	27
.4	.605	1	2	8	32
.5	.745	2	5	25	125
.6	.848	1	3	18	108
.7	.922	2	7	49	343
.8	.969	1	4	32	256
.9	.992	2	9	81	729
1.0	0.500	1	5	50	500
Σ M x ORD.		9.653	30.944	224.786	1753.988

C_1 = Σ M_1 x ORD. ÷ 15
= 9.653 ÷ 15 = 0.643533

C_2 = Σ M_2 x ORD. ÷ 75
= 30.944 ÷ 75 = 0.412587

C_3 = Σ M_3 x ORD. ÷ 750
= 224.786 ÷ 750 = 0.299715

C_4 = Σ M_4 x ORD. ÷ 7500
= 1753.988 ÷ 7500 = 0.233865

Figure 2. Form for calculation of curve coefficients.

CURVE _____

MULTIPLIERS CONSTANT		C_1 = 0.		C_2 = 0.		C_3 = 0.		C_4 = 0.	SUMMATION
		420C_1 =		3360C_2 =		7560C_3 =		5040C_4 =	a =
+ 30.000000	+		−		+		−		
		4200C_1 =		37800C_2 =		90720C_3 =		63000C_4 =	b =
− 435.000000	−		+		−		+		
		14700C_1 =		141120C_2 =		352800C_3 =		252000C_4 =	c =
+ 1960.000000	+		−		+		−		
		23520C_1 =		235200C_2 =		604800C_3 =		441000C_4 =	d =
− 3780.000000	−		+		−		+		
		17640C_1 =		181440C_2 =		476280C_3 =		352800C_4 =	e =
+ 3276.000000	+		−		+		−		
		5040C_1 =		52920C_2 =		141120C_3 =		105840C_4 =	f =
− 1050.000000	−		+		−		+		

Figure 3. Calculation of constant terms.

A simplified form for carrying out the above computation is shown in Fig. 2. A form for computing a, b, c, d, e, and f is given in Fig. 3.

Once the values of C_1, C_2, C_3, and C_4 have been determined, the first and second derivatives of the curve can be obtained using the forms in Fig. 4. At each station these derivatives can be combined to give the curvature at that point.

A detailed study of form curvature and its relationship to form resistance is being made. It is sufficient to say here that excessive waterline curvature results in high form resistance. Excessive curvature is due not only to rapid changes designed into the fore and aft contours of a ship, but also to unfairness due to careless construction practices. As a by-product of this curvature study, the application of this mathematical method to reduce the work required in mold loft fairing appears to be quite feasible.

FAIRING OF LINES IN THE MOLD LOFT

The general practice in the preliminary design of a ships' form is to first select a set of form parameters which will give a vessel of the general length, breadth, draft, and capacity required. Additional parameters which further define the form and which experience has shown will give the desired speed characteristics are then introduced. The profile endings and midship section are roughed in and a sectional area curve is selected. From this information the first lines drawing can be prepared. This lines drawing is modified and the basic parameters compromised until the most suitable set of lines is evolved incorporating the maximum number of desired characteristics.

The final lines drawing is prepared to as large a scale as possible commensurate with the available drafting facilities. These lines are faired accurately to the "thickness of a pencil line." From these lines, offsets are taken at station locations of waterline half-breadths, buttocks, diagonals, deck lines, and bow and stern profiles. The offsets are sent to the mold loft for full scale layout.

Even assuming the fairness of the lines drawing to be accurate to the proverbial tolerance, the transfer from the drawing to full scale is certain to introduce inaccuracies. If the lines were a $\frac{1}{4}'' = 1' - 0''$ scale drawing and the thickness of a pencil line were 0.005 inch, the tolerance would be expanded to approximately one-quarter of an inch full scale. In practice differences as large as three or four inches are not uncommon.

The fairing of a set of lines in the mold loft is a difficult and time consuming procedure. One layout method used in many mold lofts is described as follows:

First the body plan grid is carefully scribed on the loft floor. The body plan grid consists of the projection of centerline, base line, waterlines, buttocks, and diagonals. The half-breadth, buttock height, and diagonal offsets for the stations as given by the drafting room are measured out. Each station is faired in by use of about three wooden battens which have a $\frac{1}{2}'' \times 1\frac{1}{4}''$ cross section. To insure a fair curve, nails are driven into the floor at the plotted points and the batten is pulled up around the nails and held in place by retaining nails driven into the floor opposite the first set. The batten is left free to slide between the two rows of nails. Alternate nails are then pulled and the batten is allowed to spring to a naturally fair contour in successive steps. During this process the original points are adhered to as closely as possible. In other words,

$$y' = a + 2bx + 3cx^2 + 4dx^3 + 5ex^4 + 6fx^5$$

MULTIPLIERS x	CONSTANT	C_1 = 0.	C_2 = 0.	C_3 = 0.	C_4 = 0.	SUM y'
0	+ 30.0000	420.0000	3360.0000	7560.0000	5040.0000	
		+	−	+	−	
.1	− 11.7450	64.5624	819.6552	2189.5272	1593.9504	
		−	+	−	+	
.2	− 5.5680	117.1968	1002.0864	2206.3104	1412.8128	
		−	+	−	+	
.3	+ 7.3290	30.2232	42.4536	297.4104	397.2528	
		+	+	+	−	
.4	+ 9.9360	43.1424	619.3152	1792.6272	1359.5904	
		+	−	+	−	
.5	+ 1.8750	52.5000	577.5000	1417.5000	945.0000	
		+	−	+	−	
.6	− 8.1600	13.9776	79.5648	38.7072	190.3104	
		+	−	−	+	
.7	− 9.9630	26.0568	354.8664	1151.6904	966.7728	
		−	+	−	+	
.8	+ 0.6240	27.2832	315.0336	878.1696	643.5072	
		−	+	−	+	
.9	+ 14.1510	8.2824	119.9352	428.0472	419.6304	
		+	−	+	−	
1.0	0.0000					0.0000

$$y'' = 2b + 6cx + 12dx^2 + 20ex^3 + 30fx^4$$

MULTIPLIERS x	CONSTANT	C_1 = 0.	C_2 = 0.	C_3 = 0.	C_4 = 0.	SUM y''
0	− 870.0000	8400.00	75600.00	181440.00	126000.00	
		−	+	−	+	
.1	− 85.2300	2064.72	15681.96	33233.76	20981.52	
		−	+	−	+	
.2	+ 141.3600	530.88	7338.24	21047.04	16087.68	
		+	−	+	−	
.3	+ 89.4900	959.28	9518.04	23315.04	16112.88	
		+	−	+	−	
.4	− 36.7200	430.08	3104.64	5322.24	2378.88	
		+	−	+	−	
.5	− 108.7500	210.00	3465.00	11340.00	9450.00	
		−	+	−	+	
.6	− 73.6800	477.12	5564.16	15240.96	11329.92	
		−	+	−	+	
.7	+ 45.8100	250.32	2376.36	5110.56	2837.52	
		−	+	−	+	
.8	+ 151.4400	228.48	3104.64	10160.64	8830.08	
		+	−	+	−	
.9	+ 69.3300	354.48	4074.84	11521.44	8855.28	
		+	−	+	−	
1.0	− 450.0000	840.00	10080.00	30240.00	25200.00	
		−	+	−	+	

Figure 4. Calculation of first and second derivatives.

the best fair mean line through the plotted points is established. The station line is then chalked on the floor.

After completion of the layout of the body plan on stations, the grid for the profile is scribed on the floor. Bow and stern profiles are measured out and faired in, in the same manner used for the stations. These profiles are used to establish the waterline endings in the half-breadth plan.

Next the grid for the half-breadth plan is laid down. This consists of projections of centerline, buttock lines, and station lines. Then the half-breadth offsets as given by the drafting room are scribed on the half-breadth plan. A procedure similar to that used on the body plan is employed for fairing in the waterlines.

Once again deviation from the plotted points is inevitable. Where deviations occur, the new offsets must be transferred back to the body plan and the station lines re-faired. By working back and forth between the body plan and half-breadth plan it is usually possible to obtain fairness in the entire portion of the vessel above the turn of the bilge.

For the bottom of the vessel the buttocks are the most reliable fairing curves. The buttock heights are laid out on the profile. Each buttock line is individually faired by the above procedure and cross checked with the body plan until all intersections are identical. If changes are made in the body plan which reflect on the waterlines, a three-way correction must be made.

Finally the diagonals are laid out and faired on the half-breadth plan. The bilge diagonal is usually the most important in defining the turn of the bilge. Corrections indicated are then made on the stations, buttocks, and waterlines. Similarly the sheer line, deck lines, and plating sight edges are scribed in.

At this point the frame lines are scribed in on the profile and half-breadth plan. The waterline and diagonal offsets and the buttock heights are picked off these plans and transferred to the body plan where the frame lines are scribed in the floor.

MOLD LOFT APPLICATION OF MATHEMATICAL LINES

This detailed description of the mold loft fairing procedure has been given to illustrate the complexity of the work of the loftsman. The naval architect who is familiar with the difficulties of fairing a set of lines on the drafting board, and at the same time holding to the basic design parameters will realize the extent of the problem which faces the loftsman.

The problems of the loftsman could be diminished, and the design characteristics of the ship more closely held, if a few cardinal points on the hull could be known exactly. In passing a batten through a station line in the body plan, the fairing would be simplified if four points were definitely established. Through the use of mathematical fairing this simplification is possible.

Assume that three longitudinal curves of the ships' form are absolutely defined — the bilge diagonal, the load waterline, and the uppermost waterline (or deck line). For each station or frame in the body plan the batten could be held at these three intersections and at the intersection of keel and centerline. The fairing of the remaining waterline intersections would then be relatively easy and cross fairing with the half-breadth plan and profile would be greatly simplified.

The fitting of mathematical curves to the designed ship's curves can be done in the drafting office. Exact offsets at frames, to any required number of significant figures, can be supplied to the mold loft. This process requires some laborious computation

but should save valuable layout time in the loft.

To perform these computations, the general method given earlier is used. A typical vessel of single screw, merchant type form has been selected to illustrate, in a practical manner, the application of this method. The applicable principal dimensions of this vessel are:

Length between perpendiculars	400.00′
Length on load waterline	406.60′
Maximum beam	58.00′
Draft	22.50′
Depth amidships	33.00′
Station spacing	20.00′
Frame spacing	
Frames 0-10	2.00′
Frames 10-154	2.50′
Frames 154-164	2.00′
Deadrise	0
Bilge radius	6.380′
Half siding	0.232′

The curves which have been selected for this example are the 22.50 foot waterline, the 33.00 foot waterline, and the bilge diagonal. The bilge diagonal is the intersection with the hull, of a plane passing through (1) the centerline and load waterplane and (2) the floor line and the projected line of maximum beam.

The method used employs nondimensional relationships, and therefore the first step is to reduce the offsets to ratios of the maximum ordinate of the particular curve involved. Next, since the method assumes a continuous curve passing through the zero axis, it is necessary to subtract out the half siding. In Table I, these first two steps are shown. The first set of figures are offsets taken from the original lines on stations. The second set of figures are offsets in nondimensional form. In the third set of figures the half siding has been subtracted from each ordinate and the ratio of each ordinate to the new maximum ordinate has been computed. The data given in Table I are shown in graphic form in Figs. 5 and 6.

Since the method of mathematical curve fitting applies only to the curved sections it is necessary to select a new series of ordinates for each curve at ten equal abscissa spacings over the curved portion. This requires selection of the length between the point at which each curve crosses the base line and the point of tangency to the line of maximum ordinate. Due to the fact that the mathematical curve will not follow a straight line in the maximum ordinate region, it is essential that the point of tangency be carfeully measured. These points of intersection and tangency for the example curves are as follows:

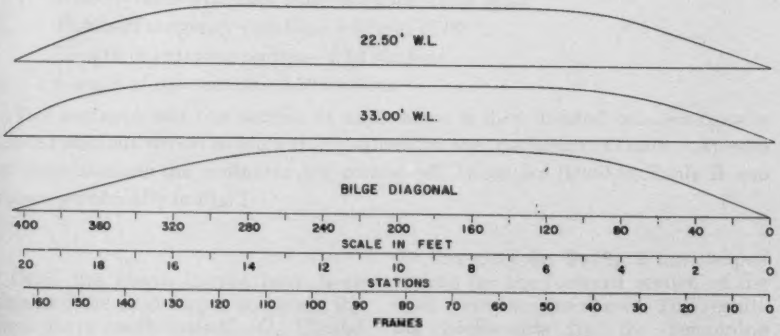


Figure 5. Original curves in true proportions.

TABLE I

Waterline and Diagonal Offsets

	Offsets in Feet			Nondimensional Offsets			Offsets Corrected for Half Siding		
Station	22.50′ WL	33.00′ WL	BD	22.50′ WL	33.00′ WL	BD	22.50′ WL	33.00′ WL	BD
F.P.	0.23	1.10	0.29	0.008	0.038	0.009	0	0.030	0
½	2.78	4.58	3.24	0.096	0.158	0.095	0.089	0.151	0.087
1	5.86	8.09	6.78	0.202	0.279	0.199	0.196	0.273	0.192
1½	8.90	11.43	10.66	0.307	0.394	0.313	0.301	0.389	0.307
2	12.32	14.67	14.61	0.425	0.506	0.429	0.420	0.502	0.424
3	18.65	20.42	21.63	0.643	0.704	0.635	0.640	0.702	0.632
4	23.78	24.80	26.91	0.820	0.855	0.790	0.819	0.854	0.788
5	27.06	27.64	30.18	0.933	0.953	0.886	0.933	0.953	0.885
6	28.59	28.86	32.22	0.986	0.995	0.946	0.986	0.995	0.945
7	29.00	29.00	33.45	1.000	1.000	0.982	1.000	1.000	0.982
8	29.00	29.00	33.99	1.000	1.000	0.998	1.000	1.000	0.998
9	29.00	29.00	34.06	1.000	1.000	1.000	1.000	1.000	1.000
10	29.00	29.00	34.06	1.000	1.000	1.000	1.000	1.000	1.000
11	29.00	29.00	34.06	1.000	1.000	1.000	1.000	1.000	1.000
12	29.00	29.00	33.69	1.000	1.000	0.989	1.000	1.000	0.989
13	29.00	29.00	32.66	1.000	1.000	0.959	1.000	1.000	0.959
14	28.94	29.00	30.82	0.998	1.000	0.905	0.998	1.000	0.904
15	28.22	28.97	28.03	0.973	0.999	0.823	0.973	0.999	0.821
16	26.42	28.48	24.05	0.911	0.982	0.706	0.910	0.982	0.703
17	23.11	27.09	19.21	0.797	0.934	0.564	0.795	0.934	0.560
18	18.04	24.10	13.22	0.622	0.831	0.388	0.619	0.830	0.382
18½	14.76	21.78	10.32	0.509	0.751	0.303	0.505	0.749	0.297
19	11.14	18.62	7.08	0.384	0.642	0.208	0.379	0.639	0.201
19½	7.34	14.50	4.29	0.253	0.500	0.126	0.247	0.496	0.118
A.P.	3.13	8.99	1.77	0.108	0.310	0.052	0.101	0.304	0.043

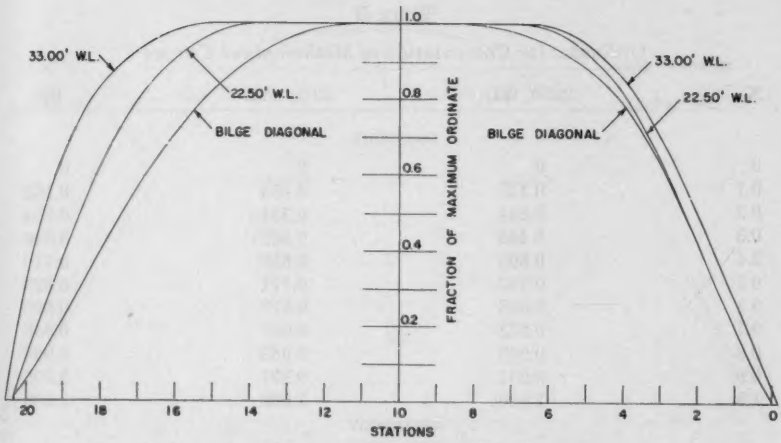


Figure 6. Original curves in non-dimensional form.

22.50′ Waterline

Intersections with base line—stations 0 and 20.33
Points of tangency—stations 7.00 and 13.45
Length of entrance section—7.00 stations
Length of run section—6.88 stations

33.00′ Waterline

Intersections with base line—stations—0.15 and 20.60
Points of tangency—stations 7.00 and 14.45
Length of entrance section—7.15 stations
Length of run section—6.15 stations

Bilge Diagonal

Intersections with base line—stations 0 and 20.33
Points of tangency—stations 8.60 and 11.00
Length of entrance section—8.60 stations
Length of run section—9.33 stations

The entrance and run section of each curve is then divided into ten equally spaced stations which become the x values for the mathematical curve. At each of these stations the ordinates are picked off. These are listed in Table II and shown graphically in Fig. 7.

Once the above curves have been obtained the next step is to obtain the basic form coefficients C_1, C_2, C_3 and C_4. The form shown in Fig. 2 is used for this purpose. In Fig. 8 the computations for the forward section of the load waterline are shown. The resulting coefficients for the remaining curves are given in Table III.

TABLE II

Ordinates for Computation of Mathematical Curves

X	22.50′ WL	33.00′ WL	BD
	FOREBODY		
0	0	0	0
0.1	0.129	0.163	0.162
0.2	0.284	0.334	0.354
0.3	0.443	0.502	0.546
0.4	0.600	0.650	0.710
0.5	0.740	0.771	0.823
0.6	0.848	0.872	0.898
0.7	0.922	0.942	0.948
0.8	0.969	0.982	0.980
0.9	0.992	0.997	0.995
1.0	1.000	1.000	1.000
	AFTERBODY		
1.0	1.000	1.000	1.000
0.9	0.993	0.998	0.991
0.8	0.979	0.990	0.964
0.7	0.947	0.973	0.918
0.6	0.892	0.942	0.848
0.5	0.808	0.886	0.750
0.4	0.700	0.807	0.617
0.3	0.561	0.695	0.465
0.2	0.392	0.535	0.303
0.1	0.202	0.313	0.130
0	0	0	0

TABLE III

Coefficients for Mathematical Curves

Curve	C_1	C_2	C_3	C_4
22.50′ WL				
Forebody	0.643533	0.412587	0,299715	0.233865
Afterbody	0.699000	0.431667	0.308073	0.238133
33.00′ WL				
Forebody	0.672533	0.423587	0.305145	0.237029
Afterbody	0.766933	0.454080	0.317860	0.243233
Bilge Diagonal				
Forebody	0.692667	0.431920	0.308813	0.238706
Afterbody	0.649333	0.414093	0.299963	0.233743

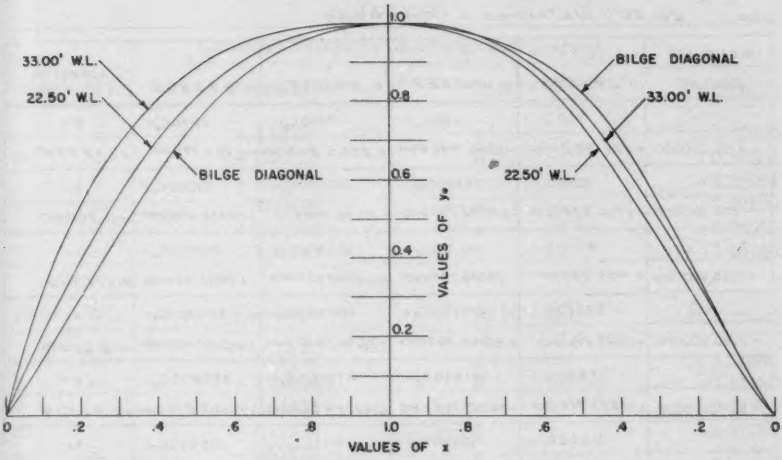


Figure 7. Corrected curves for fitting of mathematical lines.

CURVE _____

x	ORD.	M_1	M_2	M_3	M_4
0	0				
.1		2	1	1	1
.2		1	1	2	4
.3		2	3	9	27
.4		1	2	8	32
.5		2	5	25	125
.6		1	3	18	108
.7		2	7	49	343
.8		1	4	32	256
.9		2	9	81	729
1.0	0.500	1	5	50	500
Σ M x ORD.					

C_1 = Σ M_1 x ORD. ÷ 15

= _____ ÷ 15 = _____

C_2 = Σ M_2 x ORD. ÷ 75

= _____ ÷ 75 = _____

C_3 = Σ M_3 x ORD. ÷ 750

= _____ ÷ 750 = _____

C_4 = Σ M_4 x ORD. ÷ 7500

= _____ ÷ 7500 = _____

Figure 8. Sample calculation of curve coefficients.

Next the constant terms of the equation $y = ax + bx^2 + cx^3 \times dx^4 + ex^5 + fx^6$ are calculated using the form shown in Fig. 3. Again, a sample calculation for the forward section of the load waterline is given in Fig. 9 and the constant terms for the other curves are listed in Table IV.

In order to check the accuracy of these computations, the form shown in Fig. 10 is provided to calculate the ordinates of the mathematical curve corresponding to those of the original corrected curve. Table V lists the computed values for the curves used in the example.

CURVE 22.50' Waterline - Forebody

MULTIPLIERS / CONSTANT	C_1 = 0.643533	C_2 = 0.412587	C_3 = 0.299715	C_4 = 0.233865	SUMMATION
	$420C_1$ =	$3360C_2$ =	$7560C_3$ =	$5040C_4$ =	a =
+ 30.000000	+270.283860	-1386.292320	+2265.845400	-1178.679600	+1.15734
	$4200C_1$ =	$37800C_2$ =	$90720C_3$ =	$63000C_4$ =	b =
- 435.000000	-2702.838600	+15595.788600	-27190.144800	+14733.495000	+1.30020
	$14700C_1$ =	$141120C_2$ =	$352800C_3$ =	$252000C_4$ =	c =
+ 1960.000000	+9459.935100	-58224.277440	+105739.452000	-58933.980000	+1.12966
	$23520C_1$ =	$235200C_2$ =	$604800C_3$ =	$441000C_4$ =	d =
- 3780.000000	-15135.896160	+97040.462400	-181267.632000	+103134.465000	-8.60076
	$17640C_1$ =	$181440C_2$ =	$476280C_3$ =	$352800C_4$ =	e =
+ 3276.000000	+11351.922120	-74859.765280	+142748.260200	-82502.572000	+8.82504
	$5040C_1$ =	$52920C_2$ =	$141120C_3$ =	$105840C_4$ =	f =
- 1050.000000	-3243.406320	+21834.104040	-42295.760800	+24752.271600	-2.81145

Figure 9. Calculation of constant terms.

CURVE 22.50' Waterline - Forebody

CONSTANTS		MULTIPLIERS									
a =	1.15734	0.100000	0.200000	0.300000	0.400000	0.500000	0.600000	0.700000	0.800000	0.900000	1.000000
b =	1.30020	0.010000	0.040000	0.090000	0.160000	0.250000	0.360000	0.490000	0.640000	0.810000	1.000000
c =	1.12966	0.001000	0.008000	0.027000	0.064000	0.125000	0.216000	0.343000	0.512000	0.729000	1.000000
d =	-8.60076	0.000100	0.001600	0.008100	0.025600	0.062500	0.129600	0.240100	0.409600	0.656100	1.000000
e =	8.82504	0.000010	0.000320	0.002430	0.010240	0.031250	0.077760	0.168070	0.327680	0.590490	1.000000
f =	-2.81145	0.000001	0.000064	0.000729	0.004096	0.015625	0.046656	0.117649	0.262144	0.531441	1.000000
CUMULATIVE PRODUCTS	y =	.129091	.258396	.494450	.601939	.739233	.846587	.922124	.968291	.992294	1.000000
	x =	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

Figure 10. Check calculation of original curve.

To calculate the actual offsets of the full size vessel it is necessary to locate each frame exactly with respect to its position on each individual curve. As an example, the location of frame 135 on the 33.00′ waterline is accomplished in the following manner:

Distance of frame 135 from station 0

$$= 2'.00 \times 10 + 2'.50 \times 125 = 332'.50$$

$$\text{Equivalent station} = \frac{332.50}{20} = 16.625$$

Curved section of 33.00 waterline — station 14.45 to 20.60
Length of curved section — 6.15 stations $= x_1$

$$\frac{x}{x_1} = \frac{20.600 - 16.625}{6.150} = \frac{3.975}{6.150} = 0.646341$$

TABLE IV

Constant Terms for Mathematical Curves

22.50′ WL		Forebody	22.50′ WL		Afterbody
a	=	+1.15734	a	=	=2.02044
b	=	+1.30020	b	=	+0.20904
c	=	+1.12966	c	=	−2.90864
d	=	−8.60076	d	=	+1.70100
e	=	+8.82504	e	=	+0.38556
f	=	−2.81148	f	=	−0.40740

33.00′ WL		Forebody	33.00′ WL		Afterbody
a	=	+1.48158	a	=	+3.53034
b	=	+2.02260	b	=	−4.47480
c	=	−6.51434	c	=	+0.43750
d	=	+7.77924	d	=	+5.37684
e	=	−5.51376	e	=	−5.81868
f	=	+1.74468	f	=	+1.94880

BD		Forebody	BD		Afterbody
a	=	+ 1.21698	a	=	+1.02294
b	=	+ 5.33724	b	=	+3.68244
c	=	−15.03110	c	=	−7.89866
d	=	+15.29976	d	=	+5.40204
e	=	− 6.94008	e	=	−5.81868
f	=	+ 1.11720	f	=	−0.25620

TABLE V

Ordinates of Mathematical Curves

X	22.50' WL	33.00' WL	BD
		FOREBODY	
0.1	0.129091	0.162594	0.161501
0.2	0.281396	0.335899	0.358967
0.3	0.444450	0.501506	0.547484
0.4	0.601939	0.649164	0.703943
0.5	0.739233	0.773306	0.820726
0.6	0.846887	0.870826	0.900189
0.7	0.922124	0.940119	0.949957
0.8	0.968291	0.981371	0.979018
0.9	0.992294	0.998108	0.994625
1.0	1.000000	1.000000	1.000000
		AFTERBODY	
1.0	1.000000	1.000000	1.000000
0.9	0.994506	0.999200	0.990945
0.8	0.977186	0.990955	0.964251
0.7	0.944355	0.970957	0.918005
0.6	0.890675	0.937077	0.847412
0.5	0.810896	0.885826	0.748604
0.4	0.701294	0.810214	0.620341
0.3	0.560830	0.699016	0.466293
0.2	0.391999	0.537442	0.297018
0.1	0.201399	0.309205	0.131750

The second, third, fourth, fifth, and sixth powers of $\frac{x}{x_1}$ are next computed to six significant figures and substituted in the formula

$$y = a\left(\frac{x}{x_1}\right) + b\left(\frac{x}{x_1}\right)^2 + c\left(\frac{x}{x_1}\right)^3 + d\left(\frac{x}{x_1}\right)^4 + e\left(\frac{x}{x_1}\right)^5 + f\left(\frac{x}{x_1}\right)^6$$

$\left(\frac{x}{x_1}\right) = 0.646341$ $\quad a = 3.53034$ $\quad a\left(\frac{x}{x_1}\right) = 2.281803$

$\left(\frac{x}{x_1}\right)^2 = 0.417757$ $\quad b = -4.47480$ $\quad b\left(\frac{x}{x_1}\right)^2 = -1.869379$

$\left(\frac{x}{x_1}\right)^3 = 0.270013$ $\quad c = 0.43750$ $\quad c\left(\frac{x}{x_1}\right)^3 = 0.118131$

$\left(\frac{x}{x_1}\right)^4 = 0.174521$ $\quad d = 5.37684$ $\quad d\left(\frac{x}{x_1}\right)^4 = 0.938371$

$\left(\frac{x}{x_1}\right)^5 = 0.112800$ $\quad e = -5.81868$ $\quad e\left(\frac{x}{x_1}\right)^5 = -0.656347$

$\left(\frac{x}{x_1}\right)^6 = 0.072907$ $\quad f = 1.94880$ $\quad f\left(\frac{x}{x_1}\right)^6 = 0.142081$

$y = sum = 0.954660$

CURVE 22.50' waterline - Forebody

BASELINE INTERCEPT - STATION 0 MAXIMUM ORDINATE TANGENCY - STATION 7.00

MAXIMUM ORDINATE 28.765 FEET HALF SIDING 0.232 FEET LENGTH OF CURVE (x_1) 7.00 STATIONS

FRAME	FEET FROM STATION 0	STATION	STATIONS FROM INTERCEPT x	a = 1.53734 $\frac{x}{x_1}$	b = 1.30020 $\left(\frac{x}{x_1}\right)^2$	c = 1.12946 $\left(\frac{x}{x_1}\right)^3$	d = 1.60076 $\left(\frac{x}{x_1}\right)^4$	e = 1.82507 $\left(\frac{x}{x_1}\right)^5$	f = 2.51479 $\left(\frac{x}{x_1}\right)^6$	CUMULATIVE PRODUCT y	OFFSET y(MAX ORD) + H.S.
42	100.00	5.00	5.00	.714286	.510204	.364432	.260309	.185935	.132811	.930356	26.996
44	105.00	5.25	5.25	.750000	.562500	.421875	.316406	.237304	.177978	.948446	27.519
46	110.00	5.50	5.50	.785714	.617346	.485057	.381116	.299498	.235260	.963229	27.948
48	115.00	5.75	5.75	.821428	.674744	.554354	.455260	.373960	.307198	.975046	28.292
50	120.00	6.00	6.00	.857143	.734694	.629738	.539776	.462665	.396570	.984250	28.559
52	125.00	6.25	6.25	.892857	.797194	.711760	.635518	.567427	.506631	.991165	28.760
54	130.00	6.50	6.50	.928571	.862244	.800655	.743465	.690360	.641048	.996027	28.901
56	135.00	6.75	6.75	.964285	.929846	.896637	.864614	.833734	.803957	.998976	28.991
58	140.00	7.00	7.00	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	29.000

Figure 11. Calculation of mold loft offsets.

CURVE 33.00' Waterline - Forebody

BASELINE INTERCEPT - STATION -0.15 MAXIMUM ORDINATE TANGENCY - STATION 7.00

MAXIMUM ORDINATE 28.768 FEET HALF SIDING 0.232 FEET LENGTH OF CURVE (x_1) 7.15 STATIONS

FRAME	FEET FROM STATION 0	STATION	STATIONS FROM INTERCEPT x	a = 1.48158	b = 2.02260	c = -6.52434	d = 7.77924	e = -5.81376	f = 1.74468	CUMULATIVE PRODUCT y	OFFSET y(MAX.ORD) + H.S.
				$\frac{x}{x_1}$	$\left(\frac{x}{x_1}\right)^2$	$\left(\frac{x}{x_1}\right)^3$	$\left(\frac{x}{x_1}\right)^4$	$\left(\frac{x}{x_1}\right)^5$	$\left(\frac{x}{x_1}\right)^6$		
25	57.50	2.875	3.025	.423077	.178994	.075728	.032039	.013555	.005735	.680044	17.796

CURVE 22.50' Waterline - Forebody

BASELINE INTERCEPT - STATION 0 MAXIMUM ORDINATE TANGENCY - STATION 7.00

MAXIMUM ORDINATE 28.768 FEET HALF SIDING 0.232 FEET LENGTH OF CURVE (x_1) 7.00 STATIONS

FRAME	FEET FROM STATION 0	STATION	STATIONS FROM INTERCEPT x	a = 1.15734	b = 1.30020	c = 1.12946	d = -8.60076	e = 8.22504	f = -2.81148	CUMULATIVE PRODUCT y	OFFSET y(MAX.ORD) + H.S.
				$\frac{x}{x_1}$	$\left(\frac{x}{x_1}\right)^2$	$\left(\frac{x}{x_1}\right)^3$	$\left(\frac{x}{x_1}\right)^4$	$\left(\frac{x}{x_1}\right)^5$	$\left(\frac{x}{x_1}\right)^6$		
25	57.50	2.875	2.575	.410714	.168686	.069282	.028455	.011687	.004800	.673835	18.006

CURVE Bilge Diagonal - Forebody

BASELINE INTERCEPT - STATION 0 MAXIMUM ORDINATE TANGENCY - STATION 8.60

MAXIMUM ORDINATE 33.770 FEET HALF SIDING 0.294 FEET LENGTH OF CURVE (x_1) 8.60 STATIONS

FRAME	FEET FROM STATION 0	STATION	STATIONS FROM INTERCEPT x	a = 1.21698	b = 6.33724	c = -15.03110	d = 15.29976	e = -6.94008	f = 1.11720	CUMULATIVE PRODUCT y	OFFSET y(MAX.ORD) + H.S.
				$\frac{x}{x_1}$	$\left(\frac{x}{x_1}\right)^2$	$\left(\frac{x}{x_1}\right)^3$	$\left(\frac{x}{x_1}\right)^4$	$\left(\frac{x}{x_1}\right)^5$	$\left(\frac{x}{x_1}\right)^6$		
25	57.50	2.875	2.875	.334302	.111758	.037361	.012490	.004175	.001396	.605420	20.445

CURVE 33.00' Waterline - Afterbody

BASELINE INTERCEPT - STATION 20.60 MAXIMUM ORDINATE TANGENCY - STATION 14.45

MAXIMUM ORDINATE 28.768 FEET HALF SIDING 0.232 FEET LENGTH OF CURVE (x_1) 6.15 STATIONS

FRAME	FEET FROM STATION 0	STATION	STATIONS FROM INTERCEPT x	a = 3.53034	b = -9.47980	c = 8.93750	d = -5.37684	e = 1.81868	f = -0.24880	CUMULATIVE PRODUCT y	OFFSET y(MAX.ORD) + H.S.
				$\frac{x}{x_1}$	$\left(\frac{x}{x_1}\right)^2$	$\left(\frac{x}{x_1}\right)^3$	$\left(\frac{x}{x_1}\right)^4$	$\left(\frac{x}{x_1}\right)^5$	$\left(\frac{x}{x_1}\right)^6$		
160	392.00	19.60	1.00	.162602	.026439	.004299	.000699	.000114	.000019	.460744	13.457

CURVE 22.50' Waterline - Afterbody

BASELINE INTERCEPT - STATION 20.33 MAXIMUM ORDINATE TANGENCY - STATION 13.45

MAXIMUM ORDINATE 28.768 FEET HALF SIDING 0.232 FEET LENGTH OF CURVE (x_1) 6.58 STATIONS

FRAME	FEET FROM STATION 0	STATION	STATIONS FROM INTERCEPT x	a = 2.02044	b = 0.20964	c = -2.90864	d = 1.70100	e = 0.35556	f = -0.90744	CUMULATIVE PRODUCT y	OFFSET y(MAX.ORD) + H.S.
				$\frac{x}{x_1}$	$\left(\frac{x}{x_1}\right)^2$	$\left(\frac{x}{x_1}\right)^3$	$\left(\frac{x}{x_1}\right)^4$	$\left(\frac{x}{x_1}\right)^5$	$\left(\frac{x}{x_1}\right)^6$		
160	392.00	19.60	0.73	.106105	.011258	.001195	.000127	.000013	.000001	.213477	6.373

CURVE Bilge Diagonal - Afterbody

BASELINE INTERCEPT - STATION 20.33 MAXIMUM ORDINATE TANGENCY - STATION 11.00

MAXIMUM ORDINATE 33.770 FEET HALF SIDING 0.294 FEET LENGTH OF CURVE (x_1) 9.33 STATIONS

FRAME	FEET FROM STATION 0	STATION	STATIONS FROM INTERCEPT x	a = 1.02279	b = 3.63244	c = -7.87866	d = 6.40204	e = -2.95186	f = 0.45420	CUMULATIVE PRODUCT y	OFFSET y(MAX.ORD) + H.S.
				$\frac{x}{x_1}$	$\left(\frac{x}{x_1}\right)^2$	$\left(\frac{x}{x_1}\right)^3$	$\left(\frac{x}{x_1}\right)^4$	$\left(\frac{x}{x_1}\right)^5$	$\left(\frac{x}{x_1}\right)^6$		
160	392.00	19.60	0.73	.078242	.006122	.000479	.000037	.000003	.000000	.098994	3.637

Figure 12b. Calculation of mold loft offsets.

This value y represents the ratio (offset − half siding) ÷ (maximum half beam − half siding). To compute the actual offset at frame 135 we subtract the half siding from the maximum half-beam or $29.000 - 0.232 = 28.768$. This is multiplied by y or $28.768 \times 0.954660 = 27.464$. The half siding is again added to this or $27.464 + 0.232 = 27.696$ feet = offset of 33.00 foot waterline at frame 135.

The form shown in Fig. 11 has been designed to simplify this series of computations. It should be noted that six significant figures have been used throughout all calculations but that the final result is given to five significant figures. This latter number is of sufficient accuracy for mold loft work since it allows tolerances of less than 1/64th of an inch. Fig. 11 shows a typical computation for every other frame at the after end of the forebody section of the load waterline. Fig. 12 is a series of computations for one frame offset in each of the example curves.

An interesting demonstration of the accuracy of the offsets of a nominally fair curve is to take successive differences in equally spaced ordinates. To demonstrate the fairness of a mathematically derived curve relative to that of a ship faired in the mold loft by methods presently in use the following comparison is given. In Table VI are listed the offsets of a section of the load waterline forward of the parallel midsection of the VC2-S-AP3 Victory Ship. These are mold loft offsets faired to a nominal accuracy of ±1/32 inch. the first, second, and third differences are taken and these are plotted in Fig. 13. A duplicate calculation for the forebody load waterline of the example ship is shown in Table VII and plotted in Fig. 14. The superiority of the mathematical fairing is readily apparent.

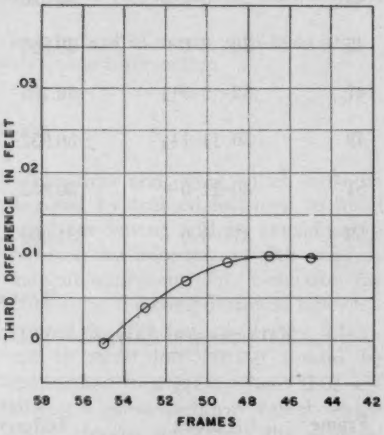


Figure 14. Mathematical waterline.

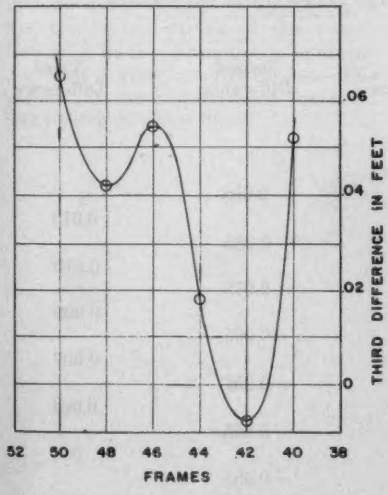


Figure 13. Victory ship waterline.

TABLE VI

VC²–S–AP3, 28′ W.L., Successive Offset Differences

Frame	Mold Loft Offset	Offset in Feet	First Difference	Second Difference	Third Difference
37	37– 3–5	27.302			
			1.146		
39	28– 5–3	28.448		—0.255	
			0.891		0.052
41	29– 4–0½	29.338		—0.203	
			0.688		—0.008
43	30– 0–2½	30.026		—0.211	
			0.477		0.018
45	30– 6–0+	30.503		— 0.193	
			0.284		0.055
47	30– 9–3½	30.786		—0.138	
			0.146		0.042
49	30–11–1½	30.932		— 0.096	
			0.050		0.065
51	30–11–6+	30.982		—0.031	
			0.018		
53	31– 0–0	31.000			

TABLE VII

Mathematical Ship, 22.5′ W.L., Successive Offset Differences

Frame	Offset	First Difference	Second Difference	Third Difference
42	26.996			
		0.520		
44	27.517		— 0.095	
		0.425		0.010
46	27.942		— 0.085	
		0.340		0.010
48	28.282		—0.075	
		0.265		0.009
50	28.547		— 0.066	
		0.199		0.007
52	28.746		—0.059	
		0.140		0.004
54	28.886		—0.055	
		0.085		0
56	28.971		—0.055	
		0.029		
58	29.000			

SUMMARY

To recapitulate, the procedure used to obtain mathematically faired offsets for specific longitudinal ships curves from the lines drawing is:

1. Reduce the ordinates to nondimensional form by taking the ratio of each ordinate to the maximum ordinate of the curve.
2. Subtract out the non-curved portion such as half siding, transom, etc. and recompute nondimensional ratios.
3. Determine longitudinal intercept of curve with base line and point of tangency with line of maximum ordinate.
4. Divide remaining curve into ten equally spaced ordinates and measure the ordinate values.
5. Compute the coefficients C_1, C_2, C_3, and C_4.
6. Compute the constant terms a, b, c, d, e, and f.
7. Perform check calculation to compare mathematical curve with original curve.
8. Determine frame locations relative to intercept of curve with base line.
9. Compute mathematical offsets for each frame intersection.

CONCLUSION

It will be noted that the computation of the offsets of only three longitudinal curves has been recommended. This does not mean that the method is inapplicable to the remainder of the fore and aft lines of the ship. However, the method shown does not yet include mathematical cross fairing of the transverse curves of the vessel. Research in this direction is continuing with a view toward further alleviation of the requirement for mold loft fairing of ships lines.

The time and effort which must be devoted by trained loftsmen to mold loft lines fairing will be considerably reduced by adoption of this mathematical approach. This reduction far outweighs the computational labor involved. In addition, the errors inherent in mold loft fairing should be diminished to a great extent thus assuring a more uniform vessel which more closely represents the original design concept.

UNDERWATER TELEVISION

ACKNOWLEDGEMENT

This is a condensed version of a paper read before The Institution of Naval Architects and The Institute of Marine Engineers, by Lieutenant Commander J. N. Bathurst, Royal Canadian Navy. It was published in the November 1954 edition of the *Transactions of the Institute of Marine Engineers.*

INTRODUCTION

The use of television under water is a post-war development which is bound to revolutionize certain diving and marine salvage techniques. The value of its application to underwater work has long been realized, but it is only through the great progress made during and since the last war in underwater optics and various electronic techniques, that it has now become a practical proposition.

Much has already been written by scientists about the technical and scientific aspects of this equipment, in particular by W. R. Stamp, B.Sc., of the Royal Naval Scientific Service, who with his team has contributed an enormous amount to its development. To date, however, no authoritative attempt has been made to set forth the practical applications, and it is therefore the object of this paper to survey some of the uses to which the equipment has already been put, and to discuss some possible future applications.

The exact value of underwater television to marine salvage and surveys is illustrated by the following extract from the discussion on a paper entitled, "Marine Salvage in Peace and War," by T. McKenzie, C.B., C.B.E., read before the Institution of Engineers and Shipbuilders in Scotland at Glasgow, in 1949. Speaking in the discussion, Professor A. M. Robb said:—

> "One of the problems in marine salvage is that the salvage officer is dependent on second-hand information as to the state of the ship, at least in many instances. It is not every Salvage Officer who is a trained diver, and he has therefore to rely on the reports of the diver as to the nature of the casualty, and then he has to train the diver to appreciate what he wants done. Thus the information and instructions are not based on first-hand inspection."

Professor Robb then went on to give an example, and Commodore McKenzie in his reply agreed.

BACKGROUND

The first successful use of television under water was achieved by the United States in 1947, and it was used by them in a static role at the Bikini atom bomb trials. The National Research Council of Canada has also carried out several successful trials, but the first really practical test it received under operational conditions occurred in May 1951, when it was used by H.M.S. *Reclaim* during the search for, and subsequent survey of, H.M. Submarine *Affray*. This particular set, which was developed at very short notice by scientists of the Royal Naval Scientific Service, proved itself very reliable, and gave excellent results. The unqualified success of this equipment made it abundantly clear that underwater television had come to stay, and pointed the way to numerous other underwater applications.

Further research and development carried out since 1951 and which is still going on, has resulted in some remarkable progress being made, so that present-day equipment is as easy of technical maintenance and operation as other shipborne electronic equipment, such as radar. There is still need, however, for development in the methods of handling and controlling the underwater camera. This is mainly because the uses to which underwater television can be put are many and varied, and the handling arrangements and design of camera casings are largely governed by the type of work for which the set is required, and the conditions under which it will operate. The whole question of camera casing design and handling arrangements will be discussed in more detail later in the paper.

The vast majority of television equipment used for underwater work to date has been the same as that used by the B.B.C. for broadcasting purposes, but incorporating certain minor modifications. This equipment makes use of a camera pick-up tube known as an Image Orthicon, which is the most sensitive type available, and naturally the associated circuitry is correspondingly complex. This high degree of sensitivity is necessary for the broadcasting application because the best possible quality of picture is required, but for closed circuit work it is unnecessarily sensitive and complex. The reason that this type of equipment has invariably been used to date is because it has been cheaper and quicker to modify what is already in production, rather than to commence the design and manufacture of special equipment for which, in the past, there has been comparatively little requirement. However, there is now an increasing demand from industry for more simplified and less sensitive equipment for a wide range of non-broadcast applications, and this is resulting in cheaper, simpler and more compact equipment becoming available. This newly developed equipment, while not producing such a high quality picture as does that used for broadcasting, is perfectly adequate for closed circuit work, and hence for the majority of underwater applications. Another type of camera pick-up tube, variously known as a Staticon, Vidicon, Emitron, etc., which is of more robust construction, can also be used, but this is less sensitive than the Image Orthicon.

SOME BASIC PROPERTIES OF UNDERWATER TELEVISION

As already stated, it is not the intention in this paper to give a technical discourse on television (the author is not so qualified, anyway), but it is necessary that certain basic properties should be understood if the practical application of this equipment to underwater work is to be fully appreciated.

First and foremost, it must be real-

ized that television is a means of vision, and is, therefore, like a diver, wholly dependent on light, contrast and water clarity for range of vision. This point cannot be stressed too much, and it must always be kept in mind when considering the application of television to underwater work. This statement needs further qualifying in that television will work at a lower light level than the human eye; in other words, it can give approximately 10-15 per cent greater range of vision than a diver will obtain under similar condtions. There are certain areas where the opacity of the water renders televison completely useless, but equally, there are large areas where it more than comes into its own. A disadvantage of television is that whereas in conditions of poor or no visibility a diver can augment what little vision he may have by a sense of touch, television lacks this. There is, however, under development a device known as the "Clear Water Container," which can be fitted in front of the camera to increase its range of vision artificially, under conditions of bad visibility.

Even in daytime, when the light level is adequate in the shallower depths, it is generally necessary to provide artificial lighting. This lighting plays an important part, not only by its intensity, but by its positioning relative to the camera, and the object being viewed. Generally speaking it should be as directional as possible, and in order to avoid back scatter, should illuminate only the minimum amount of water between the camera and the object being viewed. It should also be so placed as to ensure maximum contrast on the object by shadow effect. This also serves to give depth to the picture, but as stereoscopic vision is now possible, it will, when introduced, largely overcome the necessity for this. An instrument known as a hydrophotometer is available which will give reading of light penetration in water. Using this, the likely maximum range of televison can be predicted for any given place.

When compared with a diver, television has the following advantages:

(a) It can be used in strengths of tide far in excess of that in which a diver can operate.

(b) It has practically unlimited underwater endurance. A diver's endurance under water decreases with depth, such that in really deep work, down to say 300 ft., his underwater endurance is at the most 30 min. This also applies to an observation chamber, which, although capable of working at greater depths and in stronger tides than a suited diver, is still in fact limited in endurance.

(c) Divers and observation chamber operators are often working under conditions of severe discomfort, and mental strain, with a consequent loss of efficiency, whereas television can be operated and viewed in comfort and safety from the surface.

(d) Television can be used in depths down to 1,000 ft. at present, and is quite capable of development for use at even greater depths should the need ever arise. The maximum practical working depth for a diver is in the region of 200 ft., unless a highly trained diving team, using a special ship and equipment, is available, when it can be extended to approximately 350 ft. Any ship which can supply the requisite power, and is fitted with a derrick for handling the underwater camera, can operate television down to any depth, provided she is capable of being moored.

By filming or taking still photographs of the viewing screen, a permanent record is made available, either for subsequent inspection by persons not at the scene of operations, or for record purposes. Incidentally, the author has a theory, which has yet to be proved, that better underwater photographs will be obtained by photographing a television screen using the new techniques, than by direct underwater photography.

Several viewing screens in the ship can be operated from the main set, thereby enabling a large number of persons to view in detail any underwater operation. It is also possible for a ship to transmit over short distances to receivers ashore that which is being observed by its underwater camera.

Last, but not least, the main advantage of underwater television lies in the fact that the salvage officer or surveyor gets first-hand knowledge and is not dependent on second-hand reports from a diver, who may or may not have technical knowledge of the work he is surveying, and who at the same time is often working under conditions of mental and physical stress which may mar his judgment.

If necessary, a portable television camera can be used by a diver to augment his verbal reports, and enable the surveyor or salage officer to obtain points of detail which might otherwise be missed by a diver lacking in technical knowledge.

THE "AFFRAY" OPERATION

General

It will be remembered that in April 1951, H.M. Submarine *Affray* was lost with all hands under very tragic circumstances. The submarine disappeared without trace in the English Channel while engaged on an exercise which allowed her a considerable latitude of movement. After the first two or three days, when all hope of saving life had been abandoned, the operation resolved itself into a methodical search of some 6,000 square miles. This involved accurately locating, plotting, and positively identifying each and all the numerous wrecks existing in the area. The enormity of this task can perhaps be better appreciated when it is realized that up to the time of the actual location of the *Affray* some 250 underwater contacts had been located and classified.

It was the task of H.M.S. *Reclaim* to follow up the searching force and identify by the use of divers and observation chamber all the contacts which showed promise of being the submarine, or could not otherwise be positively identified. Owing to the strong tides, depth of water (between 30 and 50 fathoms) and the exposed nature of the area, this was an extremely exacting and laborious task.

It was the realization of these difficulties which led the Admiralty Research scientists to produce at such short notice the original equipment fitted in *Reclaim*. The author visited the Admiralty Research Laboratories at Teddington to ascertain whether or not equipment was capable of being fitted into and handled by the ship. The A.R.L. scientists had, in fact, produced a first-class workable piece of equipment which was immediately accepted.

The ship sailed within a day of its installation and the equipment was tested as soon as deep water was reached. It was a success from the start, clear pictures of the sea bed and fish being obtained during the very first submergence.

The search for *Affray* continued, but now *Reclaim* was able to identify contacts much more rapidly, since the television could be operated in stronger tides and under rougher weather conditions than a suited diver

or observation chamber. Even so, suited divers and the observation chamber were still used when possible, in conjunction with the television.

At about noon on June 14th, *Reclaim* was investagating a contact located on the edge of the Hurd Deep, about 15 miles W.N.W. of the Casquets, in about 44 fathoms, operating an observation chamber over one side and the television camera over the other. The television camera, on reaching bottom, showed the white rails round the gun position on the fore end of the conning tower. By warping the ship, the camera was quickly maneuvered to reveal the name *Affray* on the side of the conning tower.

The Original Equipment

The original set produced by the Admiralty scientists for use in H.M.S. *Reclaim* in 1951 was a standard Marconi portable type of equipment as used by the B.B.C. for outside broadcast work. No electrical modifications were made to the actual television circuits themselves, but various devices were added which are not normally necessary for ordinary working. These included a level indicator for determining the angle of the camera to the vertical, a leak indicator to show whether any water was finding its way into the pressure-tight casing which housed the camera, and a remote control of the cooling fan on the camera. This equipment was contained in four metal cases, each measuring about 8 in. × 15 in. × 24 in. These formed the complete television chain and included all the controls and one small viewing screen for the use of the operator. An ordinary English Electric commercial television set with a 15-in. screen was coupled up to the chain to enable more people to view. The power was obtained from the ship's normal 230-volt, 50-cycle a.c. mains, and the consumption was 2½ kw.

The camera was connected to the set by 500 ft. of multi-core cable, which was marked off every 10 ft. This cable was just under an inch in diameter. It was kept coiled flat on the bridge deck, and when the camera was lowered it was paid out by hand and lashed at about 25-ft. intervals to the derrick purchase wire supporting the camera. The camera was attached to the derrick purchase wire by four short wire slings and was invariably operated with the camera looking downwards about 20 deg. off the vertical. A standard 1,500-watt tungsten underwater diver's lamp, suitably shaded, was used to provide illumination. This was lashed to the camera frame, and its cable handled in a similar manner to the camera cable.

The camera itself was about 12 in. × 12 in. × 18 in., and weighed 65 lb. This was housed in a welded steel cylinder, the walls of which were 3/16 in. thick, the flat ends being ½ in. plate. The overall dimensions of this cylinder were 17 in. diameter by 24 in. long. It was mounted on a light tubular framework made up from 1 in. gas piping, the object of which was to provide a base for the camera to rest on when inboard, and to provide protection from any undue physical shocks, both when being hoisted in or out, and when under water. In addition to its carrying the underwater light, two vanes were sometimes attached to this framework to stabilize the camera when working in fairly strong tides. The actual shape and composition of this framework could be altered as desired to enable the camera to be more easily controlled when being used for different types of work. Owing to the lightness of the camera when under water, due to the buoyancy imparted to it by the pressure-tight casing, it was invariably used in conjunction with a diver's shot rope and weight, or with additional weights attached to the framework. By using the camera in conjunction with a diver's shot it was possible to exercise some very small degree of control as regards

direction in azimuth and elevation. The camera was attached to the shot rope by means of a sliding shackle, which was secured by bulldog grips to the framework. The camera was originally estimated to have a maximum working depth of just over 200 ft., but in actual practice was used quite often in depths not far short of 300 ft. The lens fitted gave a field of vision of 27 deg.

The only method of adjusting the optical settings such as focal length, and iris, or to change the lens itself, was to remove the camera from its casing. This was obviously a great disadvantage, and in order to avoid the continuous opening up of the pressure-tight casing, the camera was left "set" to suit average conditions, and a poorer quality picture accepted if the settings did not match the actual operating conditions.

Surveying the Wreck of H.M.S. Affray

It must be remembered that at this stage only limited experience in the handling of the camera under water had been gained, and therefore the preliminary overall survey was carried out using an observation chamber, but as time went on television was used more and more, either in conjunction with a diver, or completely independently.

The preliminary survey had revealed the submarine lying on an even firm bottom with a list to port of about 15 deg. and apparently undamaged, except for the snort mast which was lying over the port ballast tanks with its head resting on the sea bed.

Different divers in the observation chamber gave conflicting reports on certain detailed aspects of the submarine, such as the angle of hydroplanes, whether periscopes were up or down, and how much, etc., which tended to prove the fallibility of divers' reports given under conditions of stress. Using television, however, it was possible for a submarine expert in the ship to obtain accurate detailed first-hand information. Photographs of the television screen were also taken for the benefit of the Board of Inquiry, which was assembled ashore at Portsmouth.

Some of the uses to which the equipment was put are described in detail in the ensuing paragraphs.

(i) *Detailed Inspections.*—The television equipment was used to obtain close-up views of various parts of the submarine on which detailed information was required. To give the camera stability it was attached to a diver's shot rope by means of a sliding shackle, the camera and the shot being lowered and manipulated together, the ship being warped as necessary to position the camera over the desired part of the submarine. The television camera was able to approach much closer than the observation chamber and even though this close approach meant that the picture was slightly out of focus, it did enable very accurate information to be obtained which would not otherwise have been possible, unless a suited diver had been used, with a consequent lengthening of the operations.

(a) *Examination of Hatches.*—Close-up views of all hatches, including those for the indicator buoys, were made to ensure that no obstruction had prevented their being used. Further, to ascertain that certain hatches were locked from the inside a grapnel was attached to the shot and manipulated to hook under the salvage lugs so that strain could be applied.

(b) *Inspection of Engine-Room Telegraphs.*—Although the bridge telegraphs on the conning tower can be disconnected from the internal engine-room telegraph system it was desired to ascertain what these bridge telegraphs

were indicating. Close-up photographs were taken, which gave a clear indication of their position. Owing to the obstruction caused by the periscope standards, jumping wires, etc., it had not been possible to get this information by using the observation chamber.

(c) *Periscopes.*—Detailed and close-up photographs of the periscopes, standards, and associated equipment were taken.

(d) *Hydroplanes.*—An inspection of the after-end of the submarine from the observation chamber gave a good indication of the state of the after hydroplanes, but estimates of the angle of the forward hydroplanes, given by different observation chamber operators, varied considerably. Close-up photographs were taken using television and these then compared with those of a similar submarine. By this method it was possible to ascertain the angle of the hydroplanes to within two or three degrees.

(ii) *Inspection and Recovery of the Snort Mast.*—A close-up inspection of the break in the snort revealed a crack on the outboard side of the fairing plate, and showed that the mast was only held by a very small piece of metal. This fact had not been noticed by the divers in the observation chamber. As it was only held by such a small piece of metal it was considered feasible to recover the mast. Here again the principle of the sliding shackle and the diver's shot was used. This enabled the shot to be placed immediately alongside the head of the mast, round which it was desired to put the recovery strop. The positioning of this shot was achieved in less than half an hour. Without television it would have proved a most protracted operation. It also had the advantage that the suited diver who was detailed to place the strop could see what was needed, and have the operation described to him in detail before descending. Actually, through bad weather and strong tides, this shot had to be positioned no less than five times before it was possible for a diver to go down. After the strop had been placed, its positioning could be checked from the surface, and the second diver who was to attach the recovery wire to it was also able to see exactly what was required of him before leaving the surface. The television also ascertained that the path down the shot rope was clear of the overhanging obstructions from the periscope standards, etc., caused by the list of the submarine. The upper 28 ft. of the snort mast above the break was subsequently recovered intact, and undamaged.

(iii) *Estimation of List.*—After the recovery of the snort mast, a period of bad weather ensued, and when operations were recommenced some weeks later, it was found that the list of the submarine had increased considerably. This led to the thought that the submarine was not entirely stable, and it was decided to try to obtain accurately the angle of list, so that it could be determined whether or not the submarine was gradually rolling over on her side. This was done by lowering the diver's shot until it just touched the periscope standard spreader bars, marking the rope inboard; warping the ship just clear, and lowering the shot until it touched the sea bed, marking the rope again; and then measuring the distance between the two marks. Using this information in conjunction with a scale drawing of that section of the submarine, and knowing that the sea bed was to all intents and purposes flat, it was possible to make an accurate estimation of the degree of list. Throughout this whole operation, television only was used.

(iv) *Attempts to upright the Submarine.*—The only portion of the sub-

marine which was not available for detailed inspection was a small section of the port ballast tanks, on which she was resting. As it was desired to carry out certain work in the vicinity of the conning tower, on the port (lower) side, and not being certain that the submarine would not roll right over on to that side, it was decided that before divers should be allowed to work there, an attempt would be made to either upright the submarine, or roll her right over to starboard. This operation would determine once and for all the degree of stability and allow the remaining small area of the port ballast tanks to be inspected. Further, if successful, it would make the divers' work on the port side considerably easier. A kedge anchor on a 4½ in. Extra Special Flexible Steel Wire Rope (E.S.F.S.W.R.) was hooked into position on the after periscope standard and spreader bar. This anchor also had a 3½ in. E.S.F.S.W.R. attached to it leading to another ship. Once the anchor was in position, *Reclaim* was warped as far to starboard of the submarine as possible and the other vessel was stationed well clear on *Reclaim's* starboard side with her wire passing under *Reclaim*. At a given signal *Reclaim* applied a steady strain and the other vessel, after getting a steady strain on the wire, gradually increased speed on her engines. She was heading on a course at right angles to the fore and aft line of the submarine. The result of this operation was that the submarine did not shift, but the standards started to give, and the 3½ in. E.S.F.S.W.R. to the other ship parted. A subsequent estimation of the list of the submarine (as described above) showed that it was as before, and that therefore the submarine could be considered as having taken up a natural position on the sea bed and was stable. This whole operation was carried out entirely by television.

(v) *Removal of Casings.*—It was desired to inspect various fittings, such as the main snort induction line, certain buoyancy and ballast tank vents, etc., which lie under the upper deck casings between the after side of the conning tower and the engine-room hatch. This necessitated the complete removal of the free flooding upper deck casing in this area. For various reasons, underwater cutting and blasting could not be used, so it was decided to try and achieve this by using a kedge anchor. The kedge was slung by its gravity band in a nearly horizontal position with the object of hooking the flukes under the casing in the vicinity of the engine-room hatch to pull away the light metal from the frames. A good area of casing was removed by this method but it left a large number of jagged edges and bent and twisted frames which made it impossible for a diver to work in the very confined spaces with safety. It was decided that the only method of removing these would be by grab. An ordinary scissors grab which, at the author's instigation, had special one-foot jaws fitted, was manufactured at very short notice by Joseph Westwood and Co., Ltd., of London, and obtained on loan from Risdon Beazley, Ltd., of Southampton. This grab solved the problem and the remainder of the area was sufficiently cleared to enable divers to do their work; it was even found easily possible to grapple the individual frames and remove them. The area was subsequently cleared of any loose metal by using an ordinary electromagnetic grab which had been made pressure-tight. This whole operation was again carried out entirely by television. The light tubular framework of the camera was so adapted that it would permit the camera to give close-up views of the jaws of the grab for accurate positioning. The principle of the sliding shackle was again used, only in this case the camera was attached to the standing wire of the grab as opposed to a diver's shot.

(vi) *Photographic Records and*

Films.—Still photographs of the monitor screen were obtained in the initial instances by an ordinary camera, hand held. For easy manipulation this camera was subsequently attached to a framework which could quickly be lowered into position in front of the screen to enable a picture to be obtained when required. A large number of photographs were taken and the majority of these were submitted to the Board of Inquiry as irrefutable proof of the condition of the submarine. It must be remembered, however, that there is a very considerable loss of picture quality in these photographic reproductions of the monitor screen. In the later stages of the operation a short 16 mm. cine film was taken, which was surprisingly good considering the crude conditions under which it was taken.

SUBSEQUENT OPERATIONS BY H.M.S. *Reclaim*

In May 1952, the original equipment was removed from the ship, just a year after its installation, and a new set, which had been manufactured for the Admiralty by Pye, Ltd., of Cambridge, replaced it. This equipment embodied several new features and capitalized on the experience gained from the first year's working in so far as the design of the camera casing and handling arrangements were concerned. Once more a standard production equipment as supplied to the B.B.C. for use in their outside broadcast vans was used, and no major alterations were neces-

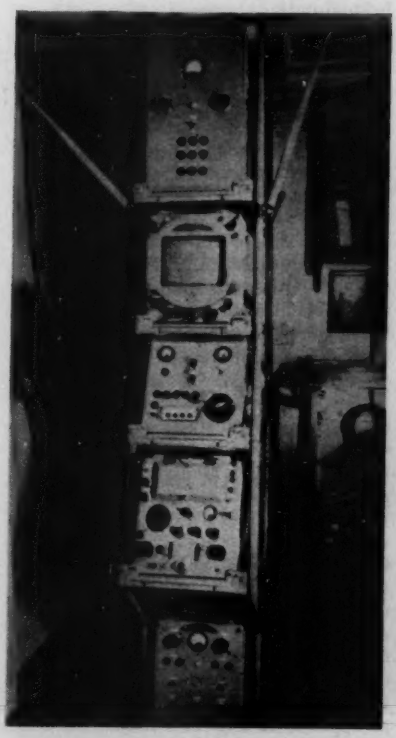


Figure 1

Figure 2

sary to the actual television circuits themselves. This equipment is illustrated in Fig. 1. It will be noticed that the components are now housed in a vertical resiliently mounted rack. This arrangement was chosen merely because it suited the space available, but naturally any arrangement of the components can be made to suit particular requirements. In addition to the tilt and leak indicators, and remote control of the cooling fan, this camera also incorporates remote control facilities for all optical adjustments. These include a motor-operated four lens turret, which allows any one of four different lenses to be selected at will, and remote focus and iris control. This marks a very big advance and enables the best quality picture to be obtained under any given set of circumstances, while the camera is underwater. The monitor screen will be seen in the second component down from the top, while the main optical controls are on the next two panels down.

The camera casing (Figs. 2, 3 and 4), which was built to the author's specification, is stream-lined for working

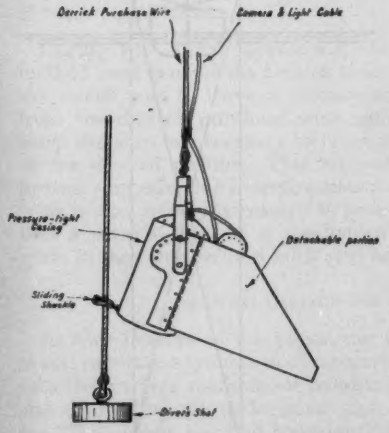


Figure 3. Method of using camera for positioning diver's shot or operating a grab.

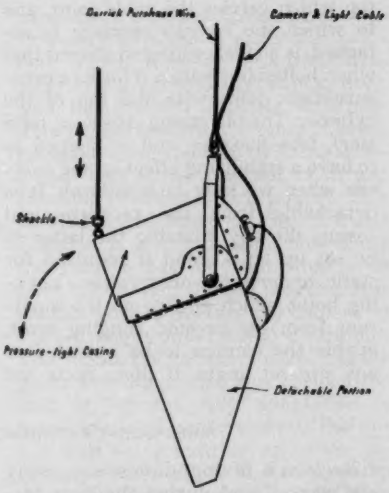


Figure 4. Method of remote elevation and azimuth control using additional light wire.

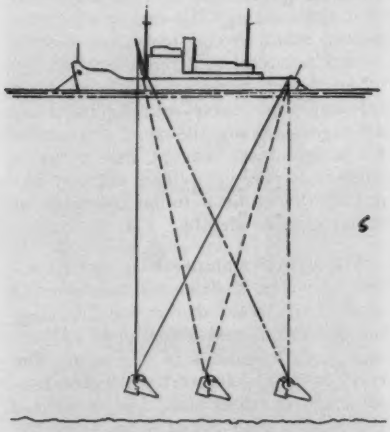
in strong tides, and is also much more robust. It has been designed to allow the camera to operate down to depths of 1,000 ft. Its total weight is 17 cwt. and the light is housed at the after-end of the tail casing. The casing was purposely made to be heavy so that it would not tend to stream out too far when being operated at depth in a tideway. The cable and its handling arrangements are the same as that for the original set, except that there is 1,000 ft. of cable provided, thereby enabling the camera to be operated at much greater depths.

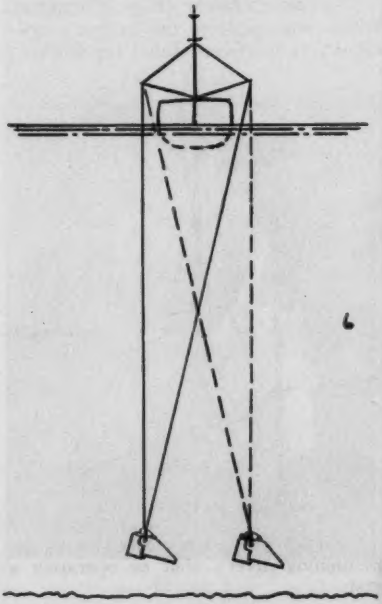
The cylindrical pressure-tight portion in which the camera is housed is made from solid-drawn steel tubing, having an internal diameter of 22½ in. and wall thickness of 11/16 in. The end plate, which carries the window, is of 1½ in. steel plate and is welded inside the tube about 4 in. from the bottom. This short projection of the tube beyond the end plate serves as a protection for the window. The domed

top which carries the cable joint, and to which the camera carriage is attached, is a steel casting so shaped that when bolted in position it forms a pressure-tight joint with the top of the cylinder. The tail casing is of ¼ in. mild steel, free flooding, and so shaped as to have a stabilizing effect on the camera when working in a tideway. It is detachable from the pressure-tight casing, thereby enabling the latter to be set up on a stand if required for static underwater observation. Locking bolts, which engage on the quadrant from the pivoted slinging arms, enable the camera to be operated at any pre-set angle. If these bolts are disengaged, the camera can be angled as desired either by a diver, or by manipulating a light wire from the surface, thereby allowing remote control in elevation. The scope of movement is from viewing vertically downwards to 15 deg. above the horizontal. This light wire, which is attached to the shackle at the front of the camera, also serves to give very effective control in azimuth. The fixed sheave visible on top of the free flooding casing is the means whereby slack on the camera and light leads is taken up inside the casing when the camera is being operated by remote control in elevation.

SUBSEQUENT EXPERIENCE WITH THIS EQUIPMENT

Reclaim's diving duties are many and varied, and during the year following the fitting of this equipment, every opportunity was taken of gaining additional experience in its use and application. This included carrying out bottom surveys, observing divers at work on set jobs, and also in conjunction with various other trials on which the ship was engaged. Basically, this work consolidated and extended the knowledge gained during the *Affray* operations in handling and controlling the camera under water. It also served to confirm that the design of the casing was on the right lines,





Figures 5 and 6. Method of using the camera for surveying a small area without moving the ship.

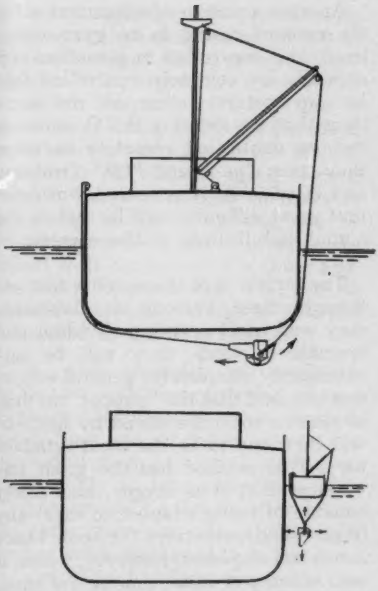


Figure 7. Methods of surveying a ship's hull.

and showed the immense possibilities of future applications.

During the *Affray* operations, the method used to move the camera about the wreck was to leave it suspended from the derrick purchase wire, and warp the ship as necessary to place it in the desired position. This method proved very effective indeed, especially as it was usually necessary to position a diver's shot, or a mechanical grab; in fact, this method must still be used under such conditions where it is necessary to plumb a particular position. When, however, it is desired to carry out a survey of a wreck, dock wall, damage to a ship, etc., it is possible for the camera to be maneuvered independent of the ship by using additional light wires attached to it, and handling it rather like a puppet. This method is illustrated in Figs. 5, 6 and 7, and it is really amazing how finely the camera can be controlled even after only a very limited practice. It is usually best to operate the camera at a fixed angle under these conditions. This method of camera control has the great advantage that it is easily capable of "on the spot" adaptation to meet any local requirements, the actual rigs being entirely up to the ingenuity of the officer in charge of the operation. Figs. 5 and 6 illustrate a rig for carrying out a survey of a totally submerged wreck lying on the bottom, or an area of the sea bed. With the camera horizontally viewing, a similar rig could also be used for surveying dock or harbor walls, lock gates, etc. Fig. 7 shows how the same principle can be applied to surveying the side and bottom of a ship. In one case portable television equipment has been embarked and the ship's own derricks, etc., are being used to handle the camera, whereas in the other, a small tender fitted with television is employed to do the survey. These are just a few of the methods of using this type of equipment, and it does not take a great deal of imagination to visualize any number of other ways in which it can be adapted for other uses.

CAMERA CASINGS AND HANDLING ARRANGEMENTS

As stated earlier in this paper, there is still room for a great deal of research into the various methods of handling and controlling the underwater camera. The author has had considerable experience of the type of equipment already described, but several other types of camera casings and handling arrangements have been evolved. Two such equipments are shown in Figs. 8 and 9. These were produced by Marconi-Siebe Gorman. The equipment shown in Fig. 8 is their original Mark I, and that in Fig. 9 their recent Mark III. It will be noticed that in both, multiple medium-powered lamps are em-

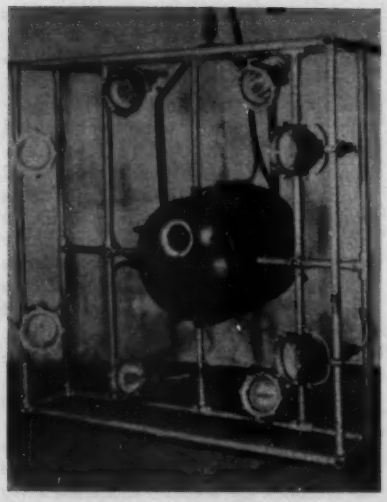


Figure 8. Marconi-Siebe Gorman Mark I camera.

ployed, as opposed to the single high-powered lamp used in equipments previously described. These lamps can be used in combinations of pairs and are manually trainable.

The Mark III equipment incorporates a recent development whereby remote optical training through 360 deg. in one plane, and 90 deg. in the other is achieved through the short transparent dome-headed periscope attachment shown at the bottom of the camera in Fig. 9. This is undoubtedly a great advance, but the illumination problem remains until such time as directional remotely controlled trainable lighting is also incorporated to work in conjunction with it. It is considered that in anything but very clear water or where the natural light is sufficient to enable artificial light to be dispensed with, the back scatter from the water caused by having lights in such close proximity to the lens is likely to have an adverse effect on the range of vision of the camera.

Another trend in development is for the camera casing to be gyro-stabilized, and controlled in elevation and azimuth, by remotely controlled follow-up motors, rather on the same lines that the existing B.B.C. cameras can be controlled remotely in what they term "pan" and "tilt" (training and elevation). It is feared, however, that great difficulty will be met in the actual stabilization of the camera.

The author is of the opinion that although these various developments may well meet certain individual and specialized needs, they will be unnecessarily complex for general everyday use, and that the "puppet" method of camera control evolved by *Reclaim* will be found to be the most satisfactory. This method has the great advantage that it is simple, and easily capable of being adapted to meet any likely requirements on the spot. There is one development, however, which is well worthy of note; that is, the small camera, which is shown in Fig. 10. This

Figure 9. Marconi-Siebe Gorman Mark III camera.

has been designed to take pressures up to an equivalent depth of about 300 ft. The total weight of the camera in air is about 70 lb., and under water it has a positive buoyancy of 1 lb.: thus it can be very easily handled by a diver or underwater swimmer. If it is desired to operate it without using divers, weights can be attached to make it negatively buoyant. Lighting can be either remote from the camera, or attached to it by means of a short arm which can be screwed on. Full remote control of optical settings is also incorporated in this small camera.

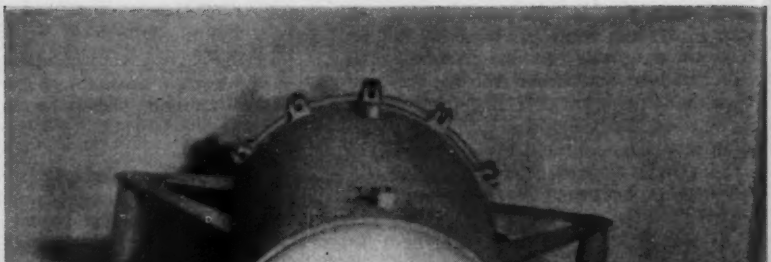
The vast majority of work in connection with the surveying of underwater damage to ships, harbor installations, etc., and ship salvage (as opposed to cargo recovery) operations is not likely to take place in depths of water exceeding 200 ft., often much less, and therefore this lightweight camera lends itself readily to this type of work. The handling arrangements and basic camera design evolved by the author in H.M.S. *Reclaim* have proved themselves to be the best for all types of general purpose work. *Reclaim's* equipment was designed, however, to enable it to operate to very great depths and therefore for the general applications being discussed in this paper it is unnecessarily heavy and robust. If, instead of the very heavy pressure-tight camera casing, the small lightweight casing was employed in conjunction with a similar type of detachable free flooding casing and/or tubular framework as used by *Reclaim*, it is considered that this would provide the most efficient means of applying television to the types of underwater work envisaged.

The methods of remote camera control for carrying out surveys, etc., illustrated in Figs. 3 to 7, could be employed, and further, with the free flooding casing detached, the camera could be used manually by a diver either to augment his verbal reports or enable a surveyor or salvage officer to obtain points of detail from the diver while actually carrying out his work. If such a camera were attached to the diver by a short, stray line, then, because it has slight positive buoyancy it would, when released, float just above him and remain within easy reach. Thus the diver could have both hands free to do any particular piece of work, on completion of which he could direct the camera on to it, and satisfy the salvage officer it was done to his satisfaction, or ask him for further directions.

ENVISAGED APPLICATIONS

Under certain conditions, television should enable a great saving in time and money to be made over the dry-docking of ships. Take, for instance, the case of a ship that has sustained underwater damage and is in need of dry-docking to effect repairs. A television survey of the damage can be made, repairs decided on, and, if necessary, new sections prefabricated before the ship ever need enter the dock. Take also the case of a ship which has sustained damage, when there are no docking facilities available; television should enable the surveyor to decide what temporary repairs are necessary, and whether or not to issue a certificate of seaworthiness. In some of the more remote places this should prove invaluable, especially when it is borne in mind that the small lightweight camera and its associated equipment, including a portable generator, is capable of being flown to the area in a small aircraft.

Except perhaps for very large salvage firms or corporations such as Lloyd's, it may well be that the very high initial cost will prevent television becoming an economic proposition, especially if it is only likely to be re-



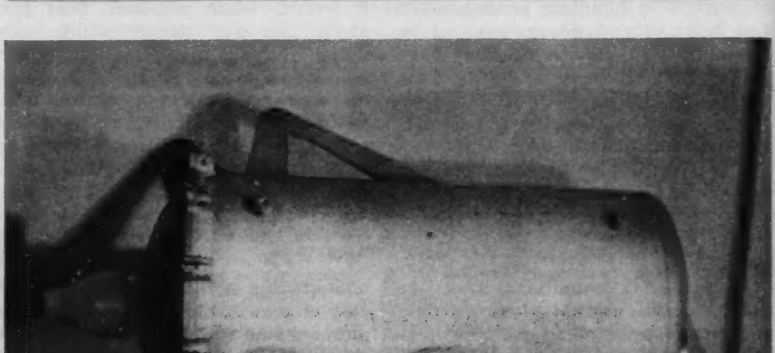


Figure 10. Pye portable camera (note size against rule).

quired for use over short periods at a time. This, coupled with the rapid developments that are taking place, and the need for the employment of special operators, leads the author to the conclusion that the only really practical and economical way in which television can be fully exploited is for the firms who manufacture the equipment to have a number of sets and operators available for hire, as and when required. This system is already employed by certain firms in connection with various types of radio and navigational aids.

Thus if a docks or harbor board required the use of equipment for a period of two or three months to carry out a particular survey, a set plus operators would be hired just for that period. This would ensure that the equipment was the most up-to-date available, and that the operators would be men fully conversant and experienced in its use. It is understood that certain firms are considering the idea, and have already got equipment which is available for hire. The efficient operation of such equipment requires a good technician, to set up and operate the electronics of the set, plus a good seaman, with a knowledge of the factors such as illumination, etc., which affect its underwater efficiency, to handle the underwater camera. It cannot be stressed too strongly that the efficient remote controlling of the underwater camera is basically common sense and good seamanship, coupled with a little ingenuity.

SUMMARY

In a paper of this length it has not been possible to go into great detail, or to discuss some of the more semi-technical problems affecting the use of television under water, but it is hoped that sufficient has been put forward to give an overall picture of the immense possibilities that it has in its application to various types of underwater work.

To date, the equipment has been successfully applied to the following:—

(a) The location and identification of underwater objects.

(b) The positioning of divers' shot ropes.

(c) The "briefing" of divers before going down.

(d) The observation and direction of divers engaged in underwater work.

(e) The operation and control of mechanical and electromagnetic grabs and grapnels when under water.

(f) The survey of underwater damage, etc.

(g) The recording of underwater operations by means of still or cine photography.

(h) The transmission of underwater pictures to other receivers remote from the ship operating the equipment.

Under certain conditions television will be able to do a diver's work more efficiently, but it is not, however, suggested that television can ever do away completely with the necessity for using divers; rather should it be regarded as a most valuable aid. It will enable the technical expert to obtain first-hand information and release him from being entirely dependent on the

reports of divers, who, as pointed out earlier, may or may not be technically capable of accurately summing up the situation, and whose reports are not always entirely infallible, owing to the conditions of mental and physical stress under which the divers may be working. It will also enable work to be carried out under conditions which would be impossible for a diver.

It is perhaps as well to end on a warning note; in spite of its immense possibilities, the fact that television is dependent for its efficiency on water clarity, lighting, etc., must not be lost sight of. Television will be little or no use in some areas where the water is very dirty, until such time as the clear water container now under development is available. A hydrophotometer survey can, however, quickly ascertain the efficiency to be expected from television in any particular area.

ATOMIC ENERGY

ACKNOWLEDGEMENT

This article, written by E. C. Pigott, Chief Chemist and Metallurgist of the Central Marine Engine Works, West Hartlepool, England, appeared in Volume I, No. 14, 1954 issue of the *Murex Review*. References to atomic energy are usually so scattered and disjointed as to afford little indication of the pattern as a whole. To remedy this situation, Mr. Pigott has traced the stage-by-stage evolution of atomic energy from the days of Ancient Greece up to the present time.

PART I. FOUNDATIONS

The Atomic Theory

Even the ancients realized that there must be a limit to the divisibility of matter. They knew that the process of repeated division cannot proceed indefinitely but must eventually lead to indivisible, fundamental particles. The Greek philosopher Democritus (460-400 B.C.) conceived of all things as consisting of atoms, varying in size and in shape. (More than twenty centuries later his theory was revived; it was to lead to our modern chemical and physical theories.)

It was the first milestone, so to speak. The second was reached when it was established by Joseph Louis Proust (1755-1826), an eminent French chemist, that, chemically, the atoms of a given element do not vary in weight, while those of different elements are definitely unlike. That is to say that all atoms of iron, for example, are always identical but that they differ from oxygen atoms or sulphur atoms. Proust could not have put forward his theory concerning atoms but for much work by other investigators concerning the true nature of an element. Previously there persisted the ancient misconception that all matter was composed of the four "elements"—fire, air, earth and water.

In 1661 Robert Boyle had glimpsed the true idea of an element. That air and water were not elements was shown respectively by A. Lavoisier in 1774 and by Joseph Priestly and Henry Cavendish in 1781. By 1789 Lavoisier was able to define an element as "the last point which analysis can reach."

Yet the creator of the atomic theory proper was John Dalton (1766-1824), the famous Quaker chemist, born not far from Cockermouth, the birthplace of Wordsworth. He was familiar with the discovery made by Sir Isaac Newton (1642-1727), the most distinguished scientist in history, that an elastic medium, such as the atmosphere, consists of particles which repel each other by a force increasing with the distance. Aware also that the atmosphere is composed of several gases of different densities, Dalton was ex-

tremely puzzled to know why the heavier gases failed to settle into lower layers. It was in 1803 that it occurred to him that a difference in size of the particles would explain this, and he at once proceeded to study their relative weights. This brought him certain confirmation that the atoms of a given element are all alike, as well as to the discovery that all compounds—ammonia or salt, for example—are formed by the union, in simple ratios, of atoms of different elements. In formulating these laws Dalton gave us the theoretical foundation of chemistry, placing the subject on a scientific basis for all time. It was still assumed, of course, that the atoms of any one element could in no way be changed into those of another element.

When employed to depict compounds, Dalton's pictorial symbols (a circle for an oxygen atom, an encircled dot for a hydrogen atom, etc.) had their limitations, but this incidental problem was solved by Berzelius, who evolved the present initial letter system.

Matter and Electricity

In 1834 came the next step. In that year Michael Faraday (1791-1867), the greatest of all experimental physicists, observed a parallel to these discoveries in the structure of electricity, which he found to consist also of particles. Ten years later Faraday saw that the relationship between matter and electricty went even beyond this, summing up his findings with the words "Particles are only centers of force; the force or forces constitute the matter."

Verification of Faraday's conclusions came when Sir William Crookes (1832-1919) started to experiment with vacuum tubes and found that matter could be decomposed into charged particles.

Divisibility

Then came the most breath-taking surprise of all: Crookes found by means of the vacuum tube that the atom, accepted by everyone as the ultimate indivisible unit of matter, a mere speck, less than a 250-millionth of an inch in diameter, could, in fact, be torn to pieces, a fate at once shared by the commonly held theory of indivisibility.

In the closing years of the nineteenth century Sir Joseph John Thompson (1856-1935) made it certain that bodies smaller than the smallest atom were in existence and put forward the theory that the atom consisted of two parts, one electrically positive, the other electrically negative. His method for studying the discharge of particles is shown in Fig. 1. In 1903 he conceived of the atom as a sphere of electric force in which electrons were rotating in planetary fashion.

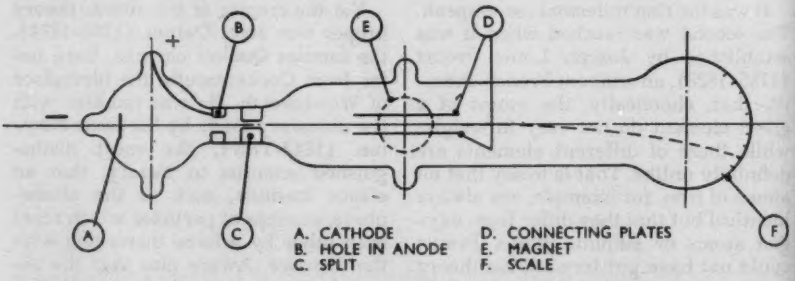


Figure 1. Rays from A in an evacuated tube pass via B to the selector slit C. An electric field is produced by a high voltage at D, and also a magnetic field by means of an external magnet.

Periodicity

Meanwhile scientific thought had been brought to bear on the relationship of the elements. in 1829 J. W. Döbereiner had noticed recurrent similarities in properties, and the more accurate the atomic weight determinations became the more this idea gathered significance. J. A. R. Newlands discovered the remarkable recurrence of properties with every eighth element, leading in 1865 to his law of octaves. In 1869 the Russian chemist D. I. Mendeleev had brought this idea to a logical conclusion by listing the elements progressively in

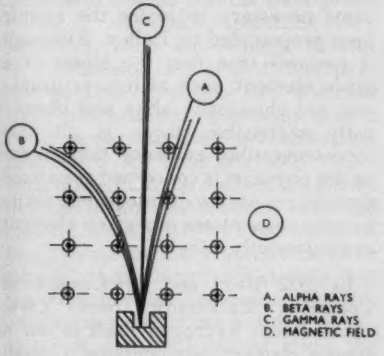


DIAGRAM OF ALPHA, BETA AND GAMMA RAYS IN MAGNETIC FIELD

Figure 2. Separation of the rays emitted by radium in the cavity of a lead block. Positive, heavy α particles are deflected to the right; negative, light β particles to left, while neutral γ-rays emerge vertically. (Marie Curie, 1903.)

eight columns according to their periodicity in properties and predicting the properties of elements then undiscovered. The repetition of properties at regular intervals came to point to similarity in internal structure.

Spontaneous Disintegration

The next clue in the astounding phenomenon of atom-smashing came with the discovery of radioactivity. Marie and Pierre Curie (1867-1930 and 1859-1906) discovered the emission of rays from uranium, radium and related elements. As shown in Fig. 2, Marie Curie identified the rays magnetically. In the hands of the brilliant New Zealander Lord Rutherford (1871-1937) this clue led to an impressive elucidation of atomic behavior. Rutherford suggested that it could be explained only by the assumption that the atoms of these radioactive elements were unstable and were continuously breaking up at rates which were characteristic for each element. He observed that even a microscopic amount of radium gave off considerable amounts of ray energy at a speed, in some cases, approaching that of light, indicating at once an immense force imprisoned within the infinitesimal atom.

Artificial Disintegration

By bombarding elements with high-velocity alpha (positively charged) particles he laid bare the nature of the atom's nucleus, showing that practically the whole mass of each atom was concentrated in a minute central nucleus carryin a positive electric charge. Around this nucleus, but at relatively very great distances, revolved elementary negative electric charges—the electrons—in numbers sufficient to neutralize exactly the positive charge of the nucleus. In 1919 he found that the bombardment of nitrogen atoms had produced hydrogen. Thus the feverish quest of the ancients—the changing of one element into another—had, in the twentieth century, become an established fact. Not only had he smashed the nitrogen atom but he had shown it to consist of the same fundamental components as hydrogen—in short, of positive and negative charges.

Rutherford, assisted by Chadwick and others, then went on to explode and transmute the atoms of boron, fluorine, aluminum and phosphorus, leading to the view that all atoms are built up of hydrogen and/or helium nuclei.

In each case a proton was ejected, and generally the process of transmutation was accompanied by the release of a constant of energy, a further indication of the store of energy resident in atomic nuclei. By 1928 he had arrived at the total internal energy of each component of the atom: 500,000 volts for the electron, and 940 million volts for the proton (positive particle). Thus when they are dislodged there is an enormous liberation of energy. "We can build heavier elements from lighter, and break up other atoms into fragments and produce novel radioactive elements by the score," summarized Rutherford.

The Rutherford conception of the atom was further developed by Niels Bohr, born in Denmark in 1885, who showed the dynamic nature of the system and evolved the best of all descriptions. He put forward a theory in 1913 which combined Rutherford's view with the quantum theory of energy which had been enunciated by Planck to explain the limitations of the classical electromagnetic theory, according to which the Rutherford system would be unstable and the energy of the revolving electrons would, in a very short time, be lost. Since 1925, however, the Rutherford-Bohr model of the atom has been looked upon as a very simplified version of the atom itself, but it has proved to be of the greatest value in explaining the results of experimental work in every branch of physics and, in particular, the relationship between different elements as regards their ordinary physical and chemical properties.

Discovery of Isotopes

Irresistibly research continued to wrench from nature one enlightening fact after another. Francis William Aston, born in Birmingham in 1877, carried out researches between 1919 and 1935 which are among the most important of any on scientific record. Following up a suggestion put forward by Soddy in 1910, Aston showed that, with few exceptions, the so-called "elements" consist of two or more true elements having whole-number atomic weights; uranium, for example, with an awkward, unnatural atomic weight of 238.07, consisting actually of elementary atoms having relative weights of 235, 238 and 239 present in such proportions as to give the average of 238.07. For the purpose of separating these *isotopes*, as they are called, he constructed an instrument known as the mass-spectograph, which responds with miraculous sensitivity to slight variations in atomic weight. It thus became necessary to revise the atomic laws propounded by Dalton. Although it remains true that the atoms of a given element, such as iron or uranium, are chemically alike and chemically indivisible, there is all this incontrovertible evidence that so far as the physicist is concerned the atoms themselves *can* be disintegrated, while in most cases atoms of a given element are *not* exactly alike.

In 1932 Urey and Brickwedde of Columbia University, New York, showed that hydrogen itself is not a simple element but contains a small amount (about one five-thousandth) of an isotope now known as heavy hydrogen, or deuterium.

Positrons and Mesons

The three main types of particles composing the atom are electrons, protons and neutrons; but in 1930 P. A. M. Dirac suspected the existence of positive electrons, and in 1932 and 1933 such particles were discovered by C. D. Anderson of California, who named them *positrons*. These rare particles are produced by cosmic rays from outer space or artificially by gamma rays. The life of a positron is about one thousand-millionth of a second. When a positron and electron unite, the charges neutralize each other, disappearing in two flashes of radiation.

In 1936 and 1937 Anderson went on to obtain evidence of the presence in cosmic rays of unstable positive and negative particles 200 times heavier than the electron and since called *mesons*. They have a life of about 10^{-6} second, and there are five varieties. Nucleons may be regarded in terms of a meson field, just as ordinary charged particles are described in terms of an electromagnetic field. The mesons then become carriers of energy quanta in the same way that photons convey energy quanta in an electromagnetic field.

Waves and Particles

The French scientist Louis de Broglie showed in 1923 that the wave properties of sub-atomic particles vary with their mass and velocity. In 1927 G. P. Thomson, son of J. J. Thomson, proved that electrons can manifest wave properties by obtaining from a rapid stream of electrons diffraction patterns of the kind produced by X-rays. Since then the opinion has grown that the distinction between wave and particle is artificial, the two conditions being complementary. About the same time W. Heisenberg made it clear that the experimental procedure used for establishing either the position or velocity of a particle would affect the other, this being due not to experimental error but to a fundamental principle of nature. For bodies of ordinary mass this uncertainty is negligible, but Newtonian mechanics become inapplicable to sub-atomic particles. Electrons are less like rotating particles than fluctuating pulsations. The Austrian physicist E. Schrödinger devised for the study of such minute particles the principle that there is a statistical probability that a particle will occupy a given position.

The reliability of these concepts and their equations has been confirmed in many ways. A stream of particles has wave-like properties owing to the probability function, and conversely this function accounts for the particle-like features of electromagnetic waves.

Atomic Nucleus

Within a year of the discovery of neutrons W. Heisenberg showed by wave mechanics that if the nucleus contains only protons and neutrons, which in the main is now accepted, then the forces of attraction would account for the known stability. Protons repel each other, while neutrons have no charge: hence the nuclear binding forces are quite distinct from ordinary electrical forces and are infinitely more powerful than those holding the electron within the atom. Binding energies of various nuclei are shown in Fig. 3. Not only are the binding forces connected with mesons, but there are group-levels or "shells" of nucleons (protons and neutrons) just as there are of the surrounding electrons.

Only certain combinations of neutrons and protons provide a stable nu-

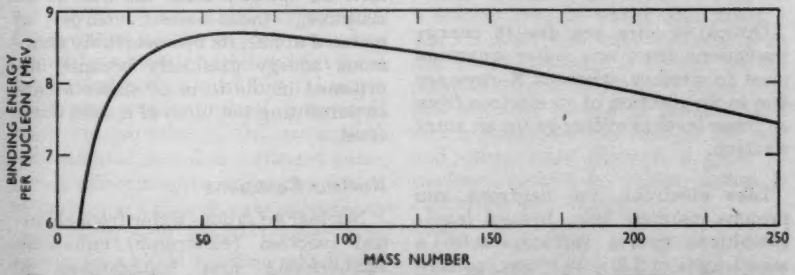


Figure 3. Binding energy of mass numbers 40 to 120 approaches 8.4 MEV per nucleon, the value for higher mass numbers falling to 7.5 MEV for uranium.

cleus. The nuclear system of two protons and two neutrons is so stable as to survive atomic disruption. All even-number configurations are more stable than those constituted of odd numbers. As the nucleus becomes more complex and the repulsion between protons increases, more and more neutrons are required. Owing partly to the mutual repulsion of the bounding electrons, the atom as a whole is rarefied.

Electrons

Wave mechanics having disposed of the idea of well-defined and fixed electronic orbits, the term *orbital* is used to represent a mathematical probability. Electrons, each in the form of a light cloud of electricity, revolve in orbitals round the nucleus. No more than two electrons can occupy any given orbital or quantum level, and these two spin in opposite directions. Groups of orbitals are called shells. In the shell next to the nucleus (the K shell) the number of electrons is mathematically limited to 2; in the next (the L shell), to 8; in the next, to 18; and so on. Chemical properties depend upon the number of the electrons in the outer shell, the whole tendency being the formation of stable, complete groups of eight electrons, so accounting for the periodicity of the elements. Bohr, in his first theory, held that the orbits were circular, but that this need not be so has been proved on the basis of subsidiary quantum numbers.

Optical spectra are due to energy transitions from one outer quantum level to another, whereas X-rays are due to the ejection of an electron from an inner level in exchange for an outer electron.

Like electrons, the neutrons and protons manifest spin. Inward level-transitions evolve radiation with a wavelength of 1.2×10^{-10} cm., so corresponding to gamma rays.

The complexity of the atom becomes all the more impressive when we consider its extreme minuteness.

Atomic Dimensions

The atoms of naturally occurring elements have diameters of the order of 2×10^{-8} cm. and range in mass from 1.67×10^{-24} g. to 3.95×10^{-22} g. A speck of uranium so minute as to be invisible may contain 10^{13} atoms. Such values have been established by X-ray diffraction, electron diffraction and band spectra. The electron has a rest mass of 9.1×10^{-28} g. and a radius of about 2×10^{-13} cm. The diameter of a molecule of water is 3.4×10^{-8} cm. The mass of a proton is 1837 times that of an electron. In a quart of water magnified to the size of the earth the molecules would be smaller than footballs, while the electrons would scarcely be visible even under the best optical microscope.

Natural Elements

The negatively charged electrons revolve round the positively charged protons, producing a neutral system. The simplest and lightest atom is hydrogen, and the most complex and the heaviest naturally occurring atom is uranium. All matter consists of these units, which combine in 92 different quantities to form the 92 naturally occurring elements constituting our globe. When, 2000 million years ago, the matter comprising the earth was torn off spirally from the sun as an eruptive, incandescent surge of maimed atoms, its inconceivably enormous energy gradually became imprisoned in the form of stable atoms, so permitting the birth of a solid outer crust.

Nuclear Equations

Nuclear equations differ from chemical reaction (electronic) equations. Rutherford's first transmutation, in which nitrogen was converted into

oxygen by alpha particles (helium nuclei), is expressed as

$$_7N^{14} + {}_2He^4 \rightarrow {}_8O^{17} + {}_1H^1$$

the upper numerals denoting the mass. For short the formula may be written $N^{14}(\alpha.\rho)O^{17}$, the bracketed symbols showing that the bombarding particle was a helium nucleus and that the emitted particle was a proton.

Nuclear Machines

Early types of reactors, such as that used by Cockcroft and Walton, have given place to the cyclotron (Fig. 4), devised by E. O. Lawrence of California. In the cyclotron a steady magnetic field exerts on an electrified particle a force at right angles to its course; with increasing velocity the particle will progress spirally, rotating round a wide circle as quickly as round a narrow circle.

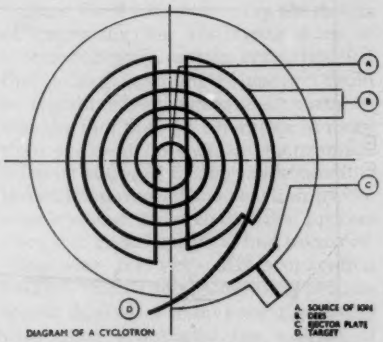


Figure 4. A high-frequency alternating potential is applied between the electrode dees, mounted in a large evacuated vessel between the poles of a powerful electromagnet. Voltage reversal accelerates the deuterons or the α particles, which thus reach the outer circumference, where they may bombard the target.

PART II. MILITARY UTILIZATION

Self-propagation

In 1932 Cockcroft and Walton bombarded the element lithium with high-velocity hydrogen nuclei. Although the release of energy was enormous for reactions involving single nuclei, the practical value of these nuclear reactions as a source of energy was still completely negligible. The reason is not far to seek: not only are such reactions very rare events, but they are not in any sense self-propagating. If we are to tap the hidden resources of energy in atomic nuclei and put them to practical use we must find a reaction which can propagate itself; a reaction involving particles of the same kind that initiated it and in sufficient numbers to affect neighboring nuclei, which in their turn will emit new particles to react with still other nuclei, thus setting up a chain reaction which will spread through the whole mass.

Mass and Energy

As predicted by Einstein, who in 1905 propounded his theory that there is no essential difference between mass and energy, the release of energy in the nuclear reaction was always accompanied by a decrease in mass. (A very small mass corresponds to a very large amount of energy; in fact, a mass of 1 oz. transferred entirely into heat energy would be sufficient to convert a million tons of water into steam!) Thus it is that the reserve of energy in the atomic nucleus is hidden in the most obvious place, its own mass. It is this store of energy in matter itself which maintains the heat of the sun and other stars through a cycle of nuclear changes in which matter is converted into energy.

Einstein's mass energy equation, which shows mass and energy to be merely different manifestations of the

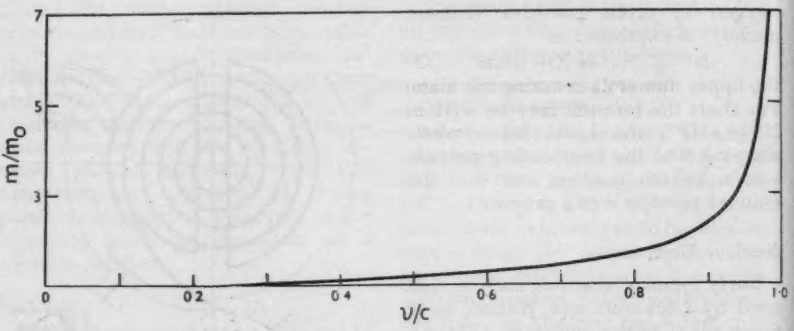


Figure 5. As the speed of a particle approaches that of light (2.9978×10^{10} cm. per sec.) there is a rapid increase in the ratio m/m_0, where m is the mass at high velocity and m_0 the rest mass.

same thing, is $E=mc^2$, where c is the velocity of light.

Energy changes within the atom have been found to comply with this equation, which shows that small amounts of mass are capable of conversion into enormous amounts of energy. If the energy is expressed in heat units, the equation becomes

E (calories) $= m$ (grams) $\times 2.15 \times 10^{13}$

Applying this equation to the decrease in mass upon the ignition of a kilogram of fuel oil to yield ten million calories, we find that

$$10^7 = m \times 2.15 \times 10^{13}$$

or

$$m = 4.65 \times 10^{-7}$$

Thus the loss of mass (4.65×10^{-7}) is far below the sensitivity of the microbalance, and this explains why mass energy conversions are not observed in ordinary chemical reactions. Yet, when considering atomic particles, mass-energy relationships are of the utmost importance. At a velocity of 20,000 miles per second a particle acquires a 1% increase in mass. The increase in mass at various velocities is shown in Fig. 5

Uranium

Uranium, the essential component of the atomic bomb, occurs mainly as a compound with lead and oxygen, the mineral being known as pitchblende. Uranium metal, discovered in 1786 by Klaproth, has the appearance of polished iron, and is very ductile. Although the British Empire and the United States have a practical monopoly of uranium minerals, there are also large deposits in the French possession of Madagascar. Most of the £500,000,000 spent on wartime atomic research and production was used in extracting the 235 isotope, present only to the extent of about 0.7% of the metal as a whole. A ton of rich uranium ore yields less than 11 lbs. of this special isotope.

An important characteristic of the uranium atom is its radioactivity—that is, its capacity for spontaneously throwing off part of its positively charged nucleus. Such an occurrence, however, is rare.

Neutrons

Sir James Chadwick, in 1932, discovered neutral particles in which a proton and an electron are closely allied. That discovery was to have a very important bearing on the tapping of atomic energy. He had been examining certain radiations emitted by polonium—a natural radioactive element—and had found these to consist

of fundamental particles in each of which a proton and an electron were closely united. They had a mass almost that of a proton but had no electric charge. These were the particles to be named *neutrons;* together with protons, etc., they constitute the nuclei of the atoms of all elements. Here was the answer to the physicist's prayer. Here, in short, was a particle whose lack of electric charge made it an ideal projectile for carrying out nuclear transformations. It was therefore no matter for surprise that it quickly became a research weapon in physics laboratories throughout the world. It could be made in quantities either by mixing polonium (or radium itself) with beryllium, or by the use of the highly ingenious instrument known as the cyclotron, which had been developed by E. O. Lawrence of the University of California.

Nuclear Fission

In 1938 Professor O. Hahn and Dr. Strassmann of Berlin proved that one of several new isotopes obtained by neutronic bombardment of uranium was actually an isotope of the element barium, which has an atomic weight about half that of uranium. Dr. Frisch and Professor Lise Meitner were quick to point out that the nuclear reaction which had taken place here was of an entirely new kind, for the uranium nucleus, they said, must have split into two parts of roughly equal weight. To this remarkable phenomenon they applied the name that was soon to make headlines—nuclear fission—and they explained that in view of the great difference in mass of the reactants and products the two fragments of the uranium nucleus would fly apart with great energy. Confirmation that this was so came in from physicists throughout the world. Professor Curie-Joliot of France, son-in-law of Madame Curie, found experimental proof that more than one free neutron was produced with each fission.

Here, for the first time, lay the means of exploiting the enormous store of atomic energy in matter. It was not just that a large amount of energy could be tapped; of much greater importance was the fact that the liberation of more than one neutron each time a uranium nucleus suffered fission made possible the *continuation* of the reaction by the development of a chain-like process once the initial splitting had occurred. Here was the very self-propagation needed. Such a self-generating process would take place at an ever-increasing rate until eventually the release of energy would be overwhelming and out of all proportion to the energy initially applied.

Professor Bohr accurately predicted that the rare isotope thorium-235 would also respond to the bombarding neutrons if of low velocity. It was found in addition that the isotope thorium-232 undergoes fission even if the bombarding neutrons have very high energy. Still other responsive nuclei include those of plutonium-239 and protactinium-231.

In 1934 the Italian physicist E. Fermi reported that by bombarding uranium with slow neutrons he had produced new elements heavier than uranium. It was five years later that Hahn and Strassmann obtained related evidence which to L. Meitner and O. R. Frisch had special significance as we have seen. In a letter dated 16th January 1939 and published in *Nature,* Meitner and Frisch stated: "It seems possible that the uranium atom has only small stability of form and may, after neutron capture, divide itself into two nuclei of roughly equal size." Further, they suggested that owing to the high neutron-proton ratio of the fission fragments, these should undergo a chain of beta disintegrations. The fragments should fly apart, producing ionization, a feature confirmed by Frisch a few days later. Here was proof of nuclear fission. Confirmation came

in Europe and the United States. In fission the loss of mass is considerable, so there is great liberation of energy. The two main products are Mo^{95} and La^{139}, the isotopic weights of their stable nuclides being 94.945 and 138.955, which together with the masses of the two neutrons (2×1.00897) total 235.918. Accordingly, the mass converted into released energy is $236.133 - 235.918 = 0.215$ atomic weight unit

Applying the factor of 921 for converting this into the energy equivalent of mass, we obtain a fission energy value of 198 MEV, an MEV being a million electron-volts.

This total energy (two million times, per unit weight, that provided by burning oil or anthracite) is divided, in MEV, as follows:

Kinetic energy of fission fragments	162
Radioactive decay energy	21
Energy of neutrons	6
Instantaneous Gamma-ray energy	3
Other energy	3
	198

Moderators

Before slow-neutron chain reaction tests could be carried out a suitable moderating material had to be found. In this country and in Germany heavy water was tried; in the United States highly pure graphite was shown to be successful. A fast neutron collides about 200 times in the graphite before striking a uranium nucleus. Uranium-238 atoms split only when bombarded by fast neutrons, but uranium-235 responds to both fast and slow neutrons. About 97% of all uranium-235 nuclei undergoing fission yield two groups of products, a "light" group (mass numbers 85-104) and a "heavy" group (130-149). In all, 34 different elements are obtained, ranging from zinc (30 protons) to europium (63 protons). They are highly radioactive, being overloaded with neutrons. The fission neutrons initiate fresh fissions, so creating the self-propagating chain reaction.

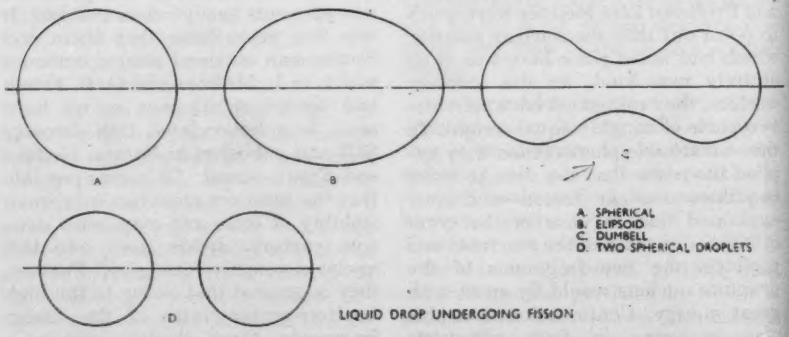


Figure 6. Owing to nuclear forces, analogous to surface tension, under which a drop assumes spherical form, the nucleus tends to remain spherical. Where the deforming force is large enough to impose a dumb-bell shape reversion is unlikely, the tendency being the division into two portions (droplets) which finally become spherical.

Fission Capacity

As with a drop of liquid (Fig. 6), an atomic nucleus receiving energy oscillates and becomes deformed, breaking then into two portions. The repulsive force of the two portions depends on the product of their positive charges, while the binding force depends on the number of nucleons. Consequently the ease of fission is related to Z^2/A, where Z is the positive charge and A the atomic number or number of nucleons. Calculations based on liquid drop behavior show that if Z^2/A exceeds 45 the repulsion is so great that the slightest deformation results in fission. The Z^2/A values of a few isotopes are as follows:

Plutonium-239	37
Uranium-233	36.4
Uranium-235	36
Tantalum	29

These values are sufficiently below 45 to necessitate appreciable extra energy for fission; the critical energy for uranium-235 is 5.3 MEV. Tantalum, the lightest element known to be capable of fission, has a critical energy of 400 MEV. From this comparison it will be appreciated why the lighter elements are unfissionable.

The fission of 1 gram of uranium per day would generate one million watts. Doubled numbers of neutrons per chain generation represent 10^{24} neutrons, or sufficient to disrupt every nucleus in 240 grams of uranium. The eightieth generation is reached in less than one-millionth of a second, since the time taken by a neutron capture (10^{-8} sec.) diminishes as the neutrons become more plentiful.

Chain Reaction Control

As suggested by F. Adler and H. von Halban in 1939, the use of the neutron-absorbing element cadmium allows the chain reaction to be retarded. Boron also is an effective controller.

The uranium isotope 238 is unsuitable for propagation of a chain reaction, since the nucleus captures neutrons, but uranium-235 and plutonium-239 are exceptionally suitable, being fissionable by slow neutrons.

Atomic Bomb Requirements

In order to bring the war to as speedy a close as possible, the first efforts directed at the utilization of this wonderful new source of energy were applied, ironically enough, to the development of an atomic bomb. Sir James Chadwick began researches at Liverpool in 1940, fully convinced of the feasibility of the power-bomb project, and within a year of the research being extended to Cambridge and Oxford many of the practical details had taken shape. Professor Curie-Joliot of France rendered conspicuous assistance by providing certain equipment, including practically the entire world stock (165 liters) of heavy water — made from the heavy isotope of hydrogen—which was used as the medium for slowing down the super-speed neutron bombardment.

The amount of uranium-235 required would be between 1 and 100 kg.; the amount would have to be greater than that at which too high a proportion of neutrons would escape into the outer air. All that would be necessary to detonate a bomb would be to bring together two pieces each less than this critical size but which when in contact would total an amount exceeding it. Even 1 lb. of affected uranium-235 would release as much energy as from 8000 tons of TNT. The most promising method for the large-scale production of the uranium-235 was that of gaseous diffusion.

Atomic Piles

In a pile the reaction would depend mainly on slow neutrons. By the early summer of 1941 the committee responsible was unanimous that the project was in every way feasible. The main problem was the construction of a plant for producing the material.

Direction of the whole plan was entrusted to the new division of the Department of Scientific and Industrial Research, with Mr. W. A. Akers as director. The original members were Professor Sir James Chadwick, Professor Peierls and Drs. Halban, Simon and Slade. Later it was joined by Sir Charles Darwin and Professors Cockcroft, Oliphant and Feather.

The uranium-235 and pure graphite would be aranged in a suitable lattice, fitted with cadmium or boron-steel control rods. Neutron escape would be minimized by means of a surrounding heavy-metal reflector.

Nuclear research in the United States was much speeded up following an official visit to this country of Professors Urey and Pegram of Columbia University. We were engaged more fully than America on war work, and it therefore appeared that large-scale researches were best conducted over there. Meanwhile our own scientists developed gaseous diffusion plant for separating uranium-235 and also plant for the large-scale production of heavy water.

The first phase, in 1942, was the production of uranium-235 and plutonium, using cyclotrons. It was known that large enough pieces would explode spontaneously.

By using volumes much smaller than 0.1 ml. and containing microgram amounts of plutonium P. L. Kirk obtained solutions containing 0.01–100 g./l. and so quite suitable for ordinary chemical reactions. In this way the chemistry of plutonium was unraveled.

On 2nd December 1942 the first man-made self-sustaining chain reaction was achieved by Fermi at Chicago after trials with smaller piles. He built nearly six tons of uranium metal, supplemented by some uranium oxide, into blocks of graphite slotted to take control rods of cadmium or boron steel. When the last rod was partly withdrawn, the multiplication factor reached unity and the neutron density rose to 200 watts.

In the early part of 1943 the British investigation was transferred to Canada and the United States, where several problems were submitted to the assault of large-scale research, methods having been devised to protect investigators from the deadly penetrating rays evolved on atomic disruption. Graphite was exploited as an alternative to heavy water for retarding the neutronic velocity. The chain-like mechanism of the explosion came to be disclosed in detail. The critical question of weight and distribution of the charge was settled. Eventually three American production plants were launched.

In 1943 a 2000 kW pilot production plant was built at Oak Ridge, Tennessee, at a cost of 12 million dollars. This cube-shaped reactor was channelled to carry uranium cylinders in cooled aluminum casings. When "poisoned" the cylinders were pushed into water, for fission-product decay, and renewed. After three months several grams of plutonium had been produced. Later, at a cost of 500 million dollars, a multi-stage gaseous diffusion plant was constructed there for separating uranium-235 from the gas uranium hexafluoride. This was completed in 1945.

Meanwhile, an electromagnetic plant for separating uranium-235 was set up at Oak Ridge also, the cost being 317 million dollars—apart from the loan by the United States Treasury of 400 million dollars worth of silver, supplies of copper being somewhat scarce. As many as 28,000 were employed on construction and 22,000 on operating this plant.

Three very large production piles were then built on Columbia River (1943–5). The plant, known as the Hanford Engineering Works, cost 350

million dollars and is still operating. The construction camp was 60,000 strong.

With the two stepping stones of Fermi's 200-watt plant at Chicago and his 2000-watt plant at Oak Ridge, the Hanford plant was based purely on the micro-chemical studies using minute amounts of plutonium, so representing a unique expansion from the laboratory stage.

Atomic Bomb Production

For actual assembly of the atomic bomb, using the uranium-235 and plutonium produced at the Oak Ridge and Hanford Works (the total dimensions exceeding the critical size), a plant was built at Los Alamos in New Mexico and placed under the direction of J. R. Oppenheimer of the University of California. Much time was spent there by Sir James Chadwick and his colleagues.

The scope of the British-Canadian-American enterprise was enlarged in 1944, and a site was selected on Ottawa River, Ontario, for the construction of a pilot scale pile.

What was the mechanism finally decided upon? While all scientific details on the construction of the 400 lb. bomb have been tightly withheld, the main features can be described with a measure of accuracy. Upon impact of the charges of uranium-235 or of plutonium-239 the already slightly unstable uranium atoms (or plutonium atoms) thunder out part of their substance in the form of bursting energy amounting to millions of volts and corresponding to millions of pounds of TNT. (Although the fissionable core is only golf-ball size, the bomb itself is very large.)

It was not necessary to supply neutrons, sufficient being produced by cosmic rays and by spontaneous fissions. The main problem was to fire one sub-critical piece into the other within a few millionths of a second. As shown in Fig. 7, disintegration had to be retarded by means of an outer envelope of heavy material, such as tungsten, to provide inertia. This dense reflection also permitted a reduction in the critical size.

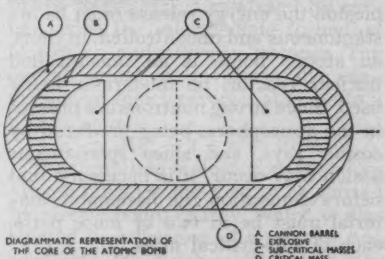


Figure 7. The dense (tungsten) barrel serves as a shield for cosmic rays, as a neutron reflector and as an explosion tamper.

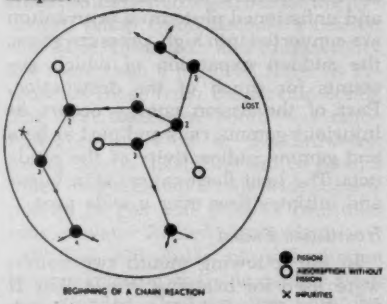


Figure 8. A neutron from the material causes Fission 1, giving two neutrons, causing Fissions 2, the neutrons from which cause Fissions 3, one of the neutrons from these being lost. Non-capture collisions occur. Fission products also are formed.

First Bomb Test

In July 1945, at Almagordo in the deserts of New Mexico, the first atomic bomb ever to be made was mounted on a steel tower 100 ft. high and exploded. There was a blinding flash brighter than sunlight, the tower being vaporized and the desert sands being fused over a large area.

The beginning of a chain reaction is shown in Fig. 8. In piles the chain reaction is set up by slow neutrons, while

the release of energy is gradual and controlled. By contrast, the chain reaction in the atomic bomb is set up by fast neutrons; in order to cause an explosion the energy release must be instantaneous and uncontrolled. In short, an atomic bomb is an uncontrolled nuclear reactor, no moderator being used. Since strong neutrons are present in the atmosphere, being produced by cosmic rays, and since spontaneous fission may occur, it is necessary that before detonation the fissionable material must be in two or more parts, each of sub-critical mass.

The explosion temperature is of the order of 10^6 degrees Centigrade, so approaching that of the sun's interior. In consequence the fission products and unfissioned plutonium or uranium are converted into high-pressure gases, the sudden expansion of which accounts for much of the destruction. Part of the fission energy occurs as injurious gamma rays and part as beta and gamma radioactivity of the products. The heat flash causes skin burns and initiates fires over a wide area.

Hostilities Ended

In the following month two bombs were used for bringing World War II to a close. The explosive energy of each was equivalent to that of 10,000–20,000 tons of TNT.

The scale was such that had a British urban area been hit, 400,000 people would have been rendered homeless and at least 50,000 of our people killed. Such would be the consequences. The effects are given in detail in Table I.

Truly mankind has unleashed a terrifying medium of new intensity which will require our loftiest powers before it is confined for all time to constructive use. It had its inception under the most diabolical war cloud in history. Yet responsible, constructive thought and effort can, if properly directed, manipulate this force to the extermination of all degrading forms of human toil. As scientists explode mystery and bring the fundamental forces of the physical universe into the open we must accept new responsibilities. The only safe outlook will be one based on the underlying causes in thought and action as distinct from mere effects.

Post-war Tests

At Bikini Atoll in mid-Pacific in July 1946 a bomb was exploded in the air and another a little way under the water to test the effect on military equipment. This operation was on a vast scale and employed 42,000 men, 242 ships and 142 aircraft. Thousands of instruments were used, as well as hundreds of pigs, goats, and mice and 5000 rats.

The shock of the first bomb depressed the sea surface many feet over a wide area. Even more spectacular was the underwater explosion, the shock pressure exceeding 5 tons per square inch and being intense even miles away. A column of water 2000 ft. wide rose more than a mile in a few seconds, to be enveloped by the huge condensation cloud. Particularly intense was the induced radioactivity, notably that from the sodium isotope.

Next, three tests were carried out at Eniwetok Atoll in the Pacific, in April and May 1948, with a team of 10,000 men.

The energy released from each of the bombs was much greater than hitherto, and all details were measured so accurately as to elucidate a great many former problems.

In 1949, when atomic blasting tests were carried out in the Urals by the Soviet Union, both plutonium and uranium-235 bombs were used. The Russians are said to have large-scale nuclear reactors in develpoment, mainly for electric power production. At no time, of course, has there been secrecy concerning the main scientific fundamentals of fission. But the highly ingenious British and American solutions to the enormous technological

problems have been guarded with the utmost vigilance. With the aid of minor leakages the Russians have found their own solutions, which however are in no way comparable with those worked out here and in the United States.

In October 1952 a British atomic bomb was exploded in the Monte Bello islands, under the supervision of Sir William Penney, who designed the exploding mechanism. When the bomb was exploded on 3rd October, experts declared the destructive power at ground level to be without precedent. The huge purple-tinted column, less mushroom-shaped than Z-shaped, had a diameter of more than a mile at the bottom and rose higher than two miles. Four minutes after the flash a thunderous roar shuddered through the mainland observation post 55 miles away. Even after fifteen minutes there was still a great intensity of heat at ground zero. For the first time British protective equipment, including shelters, clothing and anti-flash paste, were exposed to an actual atomic explosion. There is no doubt that undispersed mass armies have been rendered obsolete by such tests. Subsequently, Sir William Penney returned to the Monte Bello islands to explode a less powerful atomic bomb in the interests of research.

The Hydrogen Bomb

Following upon the atomic explosions in Russia, President Truman directed his Atomic Energy Commission to develop the hydrogen bomb, in the interests of peace and security.

Fission is only one method of releasing tremendous amounts of atomic energy. The function of the hydrogen bomb depends on the fusion of the deuterium atoms from helium atoms, the mass of the composite nucleus (4.00386) being smaller than that of the two deuterons (each 2.01473). The energy released due to "lost" mass is so enormous as to set up a cumulative reaction. The initial coalescing requires so much heat as to necessitate the use of an atomic bomb for triggering the process. Such detonation entails a large, heavy assembly.

The coalescing occurs naturally in the interior of the sun and other stars in six stages and is catalyzed by carbon, with the intermediate formation of oxygen and nitrogen isotopes. The overall equation, involving the conversion of four hydrogen atoms into a helium atom is

$$4_1H^1 = {}_2He^4 + 2 + e^0 + 27 \text{ MEV}$$

The formation of deuterons from hydrogen nuclei is too slow to be started by atomic bomb energy, which is dissipated in a fraction of a second. Accordingly the quicker deuterium-helium transmutation is exploited.

Considerable amounts of deuterium (heavy hydrogen) had to be separated from ordinary hydrogen before the hydrogen bomb could become a reality. The blast, heat flash and radioactivity are more than a hundred times as intense as those from the atomic bomb. The first hydrogen bomb was detonated on an atoll in the Eniwetok group late in 1952. The entire atoll, 3 miles long and half a mile wide, disappeared in gas and dust as countless tons of water rushed skywards.

Within 800 miles of a hydrogen bomb explosion there is danger from radioactivity. Contrast this with the fact that more than twenty atomic bombs exploded in Nevada in 1951–3 caused not a single casualty from fission products, the highest gamma radiation from towns within a 200–500 mile zone being 0.002 röntgen per hour, which is roughly equivalent to the radiation from a couple of wristwatches. That difference is one reason why civil defense schemes have had to be drastically revised. But alarm over the hydrogen bomb tends to dissolve into reassurance when we recall that in the last war the fear of reprisals restrained the enemy from engaging in chemical and bacteriological warfare. Now this new challenge to human responsibility is already meeting with a clearer recognition of the importance of proportion in international disputes.

THE ATOMIC BOMB

BLAST AND HEAT FLASH

		Blast	Heat Flash
Description		Pressure (positive) and suction (negative) waves	Intense heat from explosion
Velocity		Moderate	186,000 m.p.s.
Path		All directions	All directions in straight lines
Duration		×1 second (100 × H.E.)	1-2 seconds
Effective Range		2½ miles	2½ miles
Penetration		Poor	Poor
Effect on Exposed Persons	*Ground Zero*	Fatalities from direct pressure	100% deaths
	½ mile	Injuries from direct pressure	Skin burnt black
	Up to 1¼-2 miles	Injuries from falling masonry	Severe burns
	2½ miles	Injuries from broken glass	Minor burns
Bomb Fatalities (%)		50-60 70% of *all* casualties physically injured	20-30
Protection		Shelters, especially underground	Any building if windows covered and doors closed. Loose, white clothing best, even paper
Effect on Houses	*½ mile*	Total demolition	Probably burnt out
	1 mile	Beyond repair	Tiles blistered Concrete reddened
	1½ miles	Uninhabitable till major repairs	Wooden boards ignited
	2-2½ miles	Uninhabitable until minor repairs	In flat country especially many primary fires. In hilly country, patchy
	5 miles	Little or no effect	Bodily warmth

Description		
Velocity		
Path		
Duration		
Effective Range		
Penetration		
Effect on Exposed Persons	*Ground Zero*	
	½ mile	
	¾ mile	
	1½ miles	
Bomb Fatalities (%)		
Protection		
Symptoms		
First Aid		
Food		
Remarks		

Explosion. in 1/100th second the bomb material vaporizes, forming a ball of fire 600 ft. in diameter, which emits a dazzling flash of light, intense heat and radioactivity. Light, heat flash and gamma flash arrive together, followed by blast and sound waves, and afterwards by fission products. Losing brilliance, the ball of fire rises with hot gasses in a column to a height of many thousands of feet, then mushrooms out. Burst probably occurs 500-1000 ft. above the ground. Energy is released in one-millionth of a second.

RADIOACTIVITY

Immediate Danger		Delayed Danger	
Gamma Flash	**Neutrons**	**Fission Products**	**Induced Radioactivity**
Hard ether rays	Nuclear particles	Radioactive fragments of atoms	Artificial radioactivity caused by neutrons
186,000 m.p.s.	High	Lower than blast velocity	High-velocity emission from affected objects
All directions in straight lines	All directions	Possibly downwind	All directions
Up to 1 minute	Few seconds and induced radiation	Depends on half-life (few seconds to many years)	Depends on half-life (few seconds to many years)
1½ miles	700 yards from explosion	Ground zero also downwind, i.e. by rainstorm. Fan-shaped area if under water. Mist contaminates several square miles	Central zone
Great	Great	Great, by gamma rays emitted	Great, by gamma rays emitted
100% sudden deaths	Lethal, but outweighed by blast, heat flash and gamma flash	Serious	Serious
100% sudden deaths	None	*Radiation Meters* — Individual dosimeter (röntgens); Portable dose-rate meter (röntgens per hour)	
50 % deaths	None	Contamination meter with probe (curies); Fixed dosimeter (röntgens)	
Little or none	None	*Tol. Dose* — 0.1R per 8-hour day; .5R per 5-day week	
15-20	Few, especially if high air burst	Few, especially if high air burst	Very few, especially if high air burst
Screening by various thicknesses of material. 50% reduction by 3 ft. of concrete, none by clothing.	Away from ground zero: thick concrete	If open country, cordon off for natural decay. Evacuation Food testing	
Damaged tissues, causing radiation sickness		Radiation poisoning (by inhalation, ingestion, infection)	Risk, mainly from fission products, rarely from induced radiation
Treat for shock and injuries		Wash cuts or wounds	
No harmful effect	Destroy irradiated food, even if in airtight containers	Destroy unprotected food	
Has no contaminating effects	Radioactivity can be removed but not destroyed		

Radiations are not felt.

PART III. CONSTRUCTIVE UTILIZATION

Down the centuries, human constructive thought, by seizing hold of the more superficial facts of nature, has gained a certain control of environment. We are now faced with the stupefying responsibility of having unleashed a fraction of the real energy of the universe.

Heat and Power

As Sir Harold Hartley has pointed out, our modern civilization rests on the developments providing heat and power: James Watt's improvement of the steam engine in 1769, Fulton's steamship in 1807, the birth of the gas industry in the same year, Stephenson's *Rocket* in 1829, Faraday's discovery of electromagnetic induction in 1831 (which culminated in the first power station fifty years later), Otto's internal combustion engine in 1876, the Swan-Edison lamp in 1879, Parson's invention of the steam turbine in 1884, and the Wrights' first flight in 1903. The world's annual requirements of energy are met by burning 1400 million tons of coal, 240 million tons of wood and 50 million tons of natural gas, and generating 130,000 million units of hydroelectricity.

In other words, we have exploited so far merely stores of the sun's radiation. Now vast new possibilities are opened up to us. Conscious human thought has discerned how to arrange the atomic energy of the earth itself.

Power Plant

In any large pile enormous quantities of heat are released, and this heat should be capable of producing turbine-driving steam and so providing electrical power, as shown in Fig. 9.

Uranium provides three million times as much heat as oil or anthracite. "Bepo," our second graphite pile at Harwell, completed in 1948, has a rated output of 6000 kW. Some of this heat is removed through a heat exchanger and used for heating the buildings—a development described by Sir John Cockcroft, the Director, as "a very sound beginning in the application of nuclear power to industry."

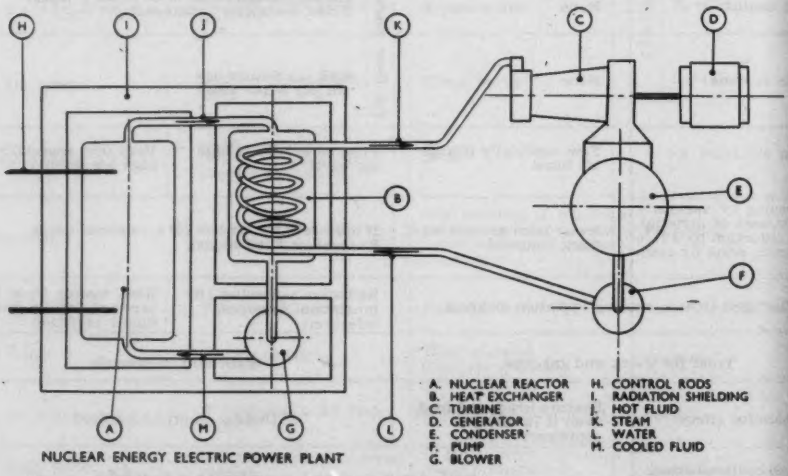


Figure 9. Circulation of the coolant through a heat-exchanger, in which the heat is transferred to water, which vaporizes.

Large-scale utilization is a complex proposition and is not likely to materialize for a decade or two. But the problems are being solved. Fission products, which could be dangerous for years, are being disposed of in heavy containers sunk in the sea, liquid wastes being stored underground until innocuous and then discharged into rivers. "Poisoned" uranium is being removed in rotation from piles for processing. New creep-resisting materials are being developed for sheathing the uranium at temperatures around 1000° C. For this purpose steel is wanting, since it is too neutron-absorbent. Aluminum serves only up to 300° C. Beryllium is more suitable, but large quantities of a ductile form would be required. Since the steam or hot gas would be radioactive it would not be passed direct to the turbine, but a heat exchanger would be used, using helium or some other inert gas or liquid bismuth; the generated steam could then drive a turbine. For a long time capital costs would be high, and even subsequently the economies might not be impressive, since the cost of fuel is greatly outweighed, even at present, by that of transmission, local distribution and administration.

It is only a matter of time before atomic energy will drive not only power plants but also ships at sea. Coal, oil and other fuels will become of steadily diminishing importance. The controlled release of atomic energy is not something that yet has to be proved; it is already an accomplished fact. One could not ask for quieter or more reliable plants than our Harwell "Bepo" or the Hanford atomic energy plant on the banks of the beautiful blue Columbia river, prototypes of the power plants of the future.

Originally the purpose of the Hanford plant was to prepare the fissionable element known as plutonium from natural uranium. The process releases astronomical quantities of heat which are readily transferred to a coolant. Generation of this heat will in the future be the primary objective. The coolant will be a high-boiling-plant fluid or compressed air, which will be led out into a heat exchanger where its energy will be turned over to water or mercury or some other substance capable of driving a turbine or other prime mover. Britain's new atomic pile at Harwell represents a great advance on the Canadian and American piles. The output is 6000 kW. Cylindrical rods of uranium are arranged among several hundred tons of graphite. On the Cumberland coast three atomic stations are seeking to apply the Harwell products to constructive use.

TABLE II. Industrial Isotopes

Source	Gamma-ray Energy (MEV)	Half-life	Output R./hr./C. at 1 M.	Type	Use
Radium, Ra	0.35	1600 years	0.83	Natural	Steel 2-6 in. thick
Radon, Rn	2.2	3.83 days	0.83	"	" 2-10 in. thick
Cobalt, Co^{60}	1.2—1.3	5.3 years	1.35	Artificial	" 2-6 in. thick
Tantalum, Ta^{182}	1.1—1.2	120 days	0.61	"	" 2-6 in. thick
Iridium, Ir^{192}	0.6	70 days	0.27	"	" ½-3 in. thick
Caesium, Cs^{137}	0.7	33 years	0.32	"	" 1-4 in. thick
Thulium, Tm^{170}	0.084	127 days	0.006	"	" less than 1/16 thick
					Light alloys less than ½ in. thick

The time taken to achieve industrial technology of nuclear energy will depend to a great extent upon engineering talent.

In view of the rarity in nature of fissionable nuclei it is tremendously fortunate that as the original fissionable substance burns away it creates a new fissionable material, none other than plutonium-239. Actually it is much easier to prepare plutonium in this way than it is to isolate U-235 from the very abundant but relatively useless natural uranium. Upon the efficiency of regeneration of fissionable material will rest the success of industrial applications of atomic energy.

Of outstanding importance is the necessity for the protection of personnel against radioactive radiation. The problem of providing adequate shields with safe openings for charging and for the entry and discharge of the cooling fluid has already been solved at the Harwell and Hanford plants. It is this essential heavy shielding that rules out, for the time being at any rate, the possibility of atomic-powered cars and aircraft. Fortunately a mere 17% increase in the shield thickness permits a tenfold increase in the nuclear activity.

Britain's giant atomic-power station at Calderhall, Cumberland, is expected to be contributing to the national grid by 1957. Treatment of the raw material, natural uranium or possibly thorium, will be carried out by a chemical section adjoining the actual power unit. It will fall to the chemical plant to remove the products of fission, namely barium, lanthanum, xenon, rubidium, selenium, tellurium, silver and ruthenium, the accumulation of which would clog the chain reaction by absorbing precious neutrons. These products are formed in a radioactive state and will be applied to such specialized uses as the painting of watch dials, to the nondestructive examination of castings, forgings and welds, and to the advanced study of chemical changes. That is the power plant of the future.

We are told by Sir John Cockcroft that a medium-size generating station will require an initial charge of 200 tons of uranium metal costing £3,000,000 and lasting 10-15 years. Cheaper nuclear power is promised by the breeder reactor, which produces plutonium and uranium^{233} from the uranium fuel, and Sir John states that if we could attain an efficiency of 60%—a value far beyond present attainments—the whole of Britain's power requirements could be obtained from an annual uranium consumption of 10 tons. Harwell's first experimental breeder reactor, built in 1953, is known as the Zephyr.

So far as existing knowledge goes, internal combustion engines, which operate by successive explosions, could not be driven by fission in any case, since fissile materials will not explode unless the critical mass is exceeded and protected.

Ship Propulsion

Atomically powered ships could remain at sea for long periods without refueling. R. T. Daniel (*Trans. Inst. Naval Architects*, 1948) envisages a heavily shielded reactor heating liquid bismuth circulating through a heat exchanger and supplying steam for a turbine, with a closed system for maintenance, for reprocessing the fissile material and for disposal of the fission products. Concentrated fissiles would be produced in land reactors. Advantages would include the freeing of bunker space and increased radius of operation—a feature of the utmost importance, especially in respect of submarines. Submarine operation would be revolutionized in other ways, since the engines would no longer require air. Submarine reactors constructed at Arco, Idaho and West Milton, N.Y., are said to hold promise.

More difficult is the application of atomic energy to aircraft propulsion, since present units are massive, but the turbo-jet principle might be modified. Such aircraft would have almost unlimited range, and the possibility is being actively studied, as shown by developments in shielding efficiency.

During the past two years more than 60% of the work at Harwell has been devoted to work on practical uses. Since the Monte Bello test the experts at Harwell and at the northern atomic stations at Selafield in Cumberland, Capenhurst in Cheshire, and Springfield in Lancashire have been able to concentrate on constructive applications, notably the development of power.

Availability of Fissionable Material

If total world heat requirements were to be met atomically, at least 150 tons of uranium would be required per annum. According to M. H. L. Pryce (*Discovery*, March 1948), a world uranium supply of 1000 tons a year, from rich ore alone, might last for ten years. But utilization will not aproach so vast a scale for many decades. Also, low-grade ores will be exploited. Meanwhile, serious prospecting for rich ores proceeds throughout the world. Thorium, which is relatively abundant, could be converted into uranium-233. The largest rich deposits of uranium are in Canada and the Belgian Congo. The chief sources of thorium are the magnetic sands found in India and Brazil.

Atomic Fusion

In the course of time it may be possible to apply atomic *fusion* to power production, and it may even prove possible to convert matter entirely into energy, in which case 1 lb. of matter would serve in place of one and a half million tons of coal. Already it is known that positrons and electrons annihilate one another, with conversion into energy. Complete conversion of the atom is not beyond the bounds of future possibility.

Isotopes

Already atomic energy is being exploited constructively on a large scale in the production of radioactive isotopes for use in research and industry. These are used largely as tracer elements. Many different isotopes are available. Between August 1946 and June 1950 12,000 consignments of radio-isotopes and 1160 consignments of stable isotopes were supplied in the United States alone, while our own plants have so large an output as to maintain considerable exports.

Thanks to the Geiger-Müller counter (Fig. 10), radio-isotopes are easy to detect and determine, but protective measures are required. A pocket dosimeter, for the protection of personnel, is shown in Fig. 11. By contrast, stable isotopes necessitate the use of the expensive and complicated mass-spectrometer, yet their physiological effects are negligible and their permanency allows tests of long duration. The specific activity (unit, the curie) is the quantity of radioactive material having 3.7×10^{10} disintegrations per second: radium has a specific activity of 1 curie per gram.

The wear of radioactive steel piston rings is measured by the radioactivity of the lubricant, while a radiograph of the cylinder discloses the areas of greatest wear, so leading to improved lubricants and components. Isotopes are used in the study of age-hardening, heat-treatment, and cold rolling, the behavior of different constituents being greatly clarified. In the investigation of creep, the movement of atoms of a metal within the crystal lattice is of much importance: only tracer elements reveal the diffusion. Isotopes are being applied to the further elucidation of blast furnace reactions. By converting coal with a small amount of added pyrite containing radioactive sulphur it was established that the ratio of organic sulphur to inorganic in coke is

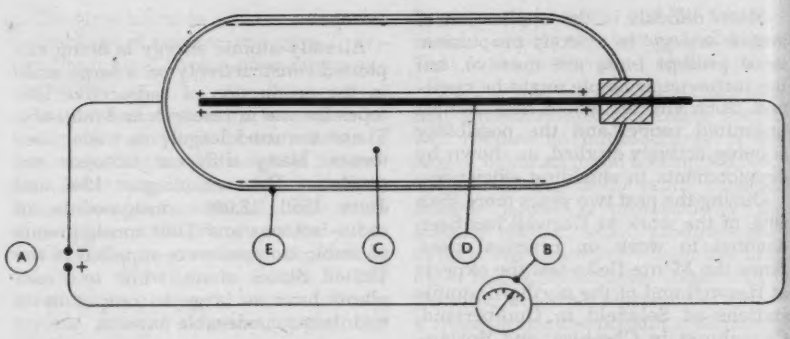


Figure 10. Ionization of the argon gas, due to α, β and γ radiation, causes a current to flow, with deflecton of the needle; when amplified, this pulse can operate a mechanical counter.

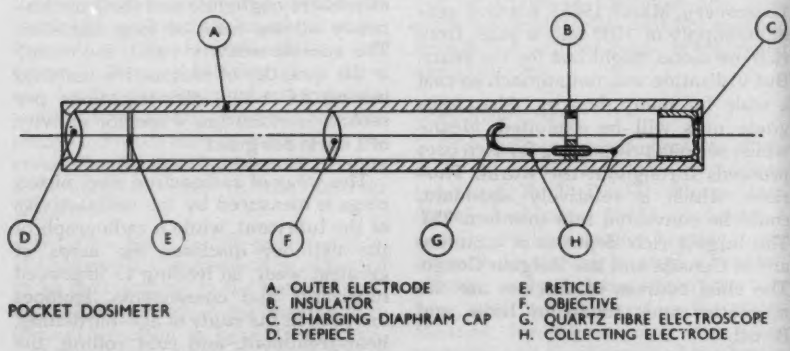


Figure 11. For protection of personnel. In this instrument, which is calibrated in milliröntgens, ionization deflects a quartz fibre on a scale, so indicating the quantity of radiation.

the same as that in the coal from which it is made.

It has been found that the cosmic rays activate carbon in wood and that "new" wood has a constant radioactivity of 12.5 counts per minute per gram of carbon, in contrast to 7 counts in wood from Egyptian tombs, thus providing a reliable age test.

One of the main applications of isotopes is their use in radiography, and an extensive range of special equipment is available. An important advantage is that any desired shape of

ordinary cobalt or other element may be irradiated with neutrons in an atomic pile. Innumerable streams of the neutrons wander into the nucleus of the atom and change the atom's properties. Details of suitable isotopes are shown in Table II.

Isotopes are also valuable in analytical work. In tracer analysis a known amount of isotopic material is added to a system in which the total quantity of a given element is known. Allowing for the known natural decay, the specific activity wll be constant, and a particle counter will then indicate variations in the total amount of the element when the system undergoes change. Isotopic dilution anlysis, a variant of the technique, requires only that the isotopic content of the element is known; decrease in content is then shown by the specific activity. Still another branch is activator analysis, in which an element which is difficult to determine is exposed to deuterons in a cyclotron or, better, to neutrons in a reactor; with one or more of the stable isotopes of the element so activated, detection and determination become possible by means of the radiations of known half-lives. This particular technique is used in the analysis of mixtures of the rare earths as well as for determining traces of gallium and palladium in iron meteorites.

In short, isotopes are tremendously useful in research and industry, and it is no matter for surprise that they are being applied on an ever-increasing scale.

The Future

So much for the impress of some aspects of science on the past and on the present. At a time when science seems to be getting out of hand and in process of turning complacency into international alarm there is every reason why the precise methods of developing and utilizing science should be looked upon increasingly as a social responsibility. Any doubt as to the importance of science in a nation's security and economic prosperity has been conclusively shattered by recent events, and the realization is gaining ground that in the world of today one of the very first demands is the proper control and planning of science on a basis of humanitarian principles.

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THE MILITARY BUDGET CYCLE

CAPTAIN JOHN D. GERWICK, USN

THE AUTHOR

was born in 1913 in Mt. Vernon, Ohio. He attended local schools prior to entering the U.S. Naval Academy from which he graduated in 1935. Following four years of general line duty in surface ships, he attended the U.S. Naval Submarine School at New London in 1939. After graduation from that school his service until the end of World War II was in various submarines; as Commanding Officer of USS *Greenling* in 1944 and 1945. During his submarine war service he was awarded the Silver Star with a Gold Star in lieu of a second award, a Navy Unit Citation and the Submarine Combat Award with four stars.

Since the war Captain Gerwick has served in several billets which include a course at the Naval War College in 1950 and 1951, and his present assignment on the Staff of the Industrial College of the Armed Forces.

One of the biggest items in your and my *cost of living* is the *cost of defense*. The Federal Budget this year is estimated at nearly one-fifth of the national income, or $400 for each man, woman, and child. Two-thirds of this money goes to National Security, $40 billion worth.

How much does defense—National Security—cost you, the average family? Defense is the third largest item in your budget. Your house is probably first, food and clothing second. But, right in there, a close third, is the cost of National Security! Most of you will pay more for taxes than for your car.

The military services are big business in a big way. Department of Defense assets are 12 times those of General Motors, Standard Oil of New Jersey, and U. S. Steel combined. Moreover, the services will purchase this year 14 times Sears Roebuck's total sales. Those sales include close to 100,000 items. The Armed Services purchase over 3 million.

How do you get this money? How do we spend it and account for it? The process is known as the "budget cycle" —a huge, complex action. It differs from that of other agencies mainly because of size—in the impact on the national economy, and the complexity of the machinery. Here we will hit only the high spots.

WHAT IS THE BUDGET?

Physically, the budget is two large volumes of intricate prose and dry-as-dust statistics. The main volume contains over 1200 finely printed pages, about the size of the Washington, D. C. phone book. The military departments fill 150 pages. A 529 page appendix on personal services is the second volume.

For easier reference there is a book of summary tables and special analyses. For yet easier reference there is a 64 page pamphlet "The Budget in Brief," with pictures. And after the Congress' action there is a 36 page "Review of the Budget"—what we really get.

Functionally, the budget is a fiscal plan for the next fiscal year. It covers the revenue and expenditure programs, with comparisons between the current and past years. As passed by the Congress it approves the performance of, and determines the priority and extent of, government services by providing appropriated funds. But, the budget is also a control, enforcing accountability for efficient execution of programs.

HISTORY

The history of the Federal Budget as we know it today really begins with the passage of the Budget and Accounting Act of 1921. Before 1921 the small size and relative simplicity of Federal appropriations permitted the confusion of a congressional committee system of financial jurisdiction. In this system, or lack of system, appropriation bills were referred piecemeal by the Departments to several of many committees. The President had little or no part in the process. There was scant coordination.

Beginning with the 1921 Act, the Executive began to plan and control expenditures. Other Acts of Congress continued to develop this system. The present history stems from the Budget and Accounting Procedures Act of 1950. The result is a comparatively adequate and orderly system of budgeting.

THE BUDGET CYCLE

The present budget cycle can be over-simplified into three phases—*formulation, adoption* and *execution.* The President takes the first step in formulation, and participates in the adoption. But his most important job comes in the third step, execution.

Congress figures most prominently in the adoption phase. Here the budget is considered, modified, and the supporting appropriation acts passed. The final product is not only approval of funds but also a statement of fiscal policy. Congress controls the appropriations, and through them controls military policy.

The President's executive agency which directs and coordinates the formulation of the budget, and executes it, is the Bureau of the Budget. The Director of this Bureau is appointed by the President to serve at his pleasure. Usually an appropriation act is only an authorization to spend and not a mandate. The President, through the Bureau of the Budget, has the power to tell the departments how much of the money to spend, and how fast to spend it.

The tools of Congress in the adoption of the budget are the Appropriation Committees. They review the President's budget and make recommendations to the two Houses. In the execution, the Congress' agency is the General Accounting Office. The head of this agency is the Comptroller General, who is required by law to review the business operations of the executive agencies. He is appointed by the President with the advice and consent of the Senate for a term of 15 years. He is not eligible for reappointment, and can be removed only by joint resolution of the

Congress for cause. Although he reports to both the President and the Congress, he is an agent of the Congress. His duties are not subject to the President's direction.

Each military department prepares and executes its own budget. The Secretary of Defense reviews and coordinates the budgets of the military departments and supervises their execution, but does not combine them.

Formulation.

Formulation of the military budget is based on a series of policies and ceilings, communicated downward from the President, the National Security Council, the Council of Economic Advisers to the President, the Office of Defense Mobilization, the Treasury, the Bureau of the Budget, the Joint Chiefs of Staff, and the Secretary of Defense. From and within these policies and ceilings, plans and programs are developed and costs estimated. Typical considerations for the estimate of funds are the following:

a. Military personnel costs.
b. Operation and maintenance.
c. Major procurement and production.
d. Military public works.
e. Research and development.
f. Reserve components.

Budget estimates are prepared in the military departments as much as two years before the beginning of the fiscal year in which they are to be spent. Since definitive direction is usually not available until late in the formulation phase, much of the work must be revised and repeated each year when new policies and force levels are made available.

Review hearings on the service estimates are held at the department level, the Secretary of Defense level, and by the Bureau of the Budget. One of the most effective tools of the Secretary of Defense in the supervision over the military departments is his control of the military budget. Following each of the review hearings the services are given a brief period in which they may submit appeals for the restoration of some of the cuts in the estimates.

In recent years the Bureau of the Budget and the Office of the Secretary of Defense reviews have been held jointly due to the shortness of time remaining after the latest policies are received. The Bureau, however, has not forfeited the right for subsequent decisions after the Secretary has completed his action.

After the final decisions by the Director of the Budget and the President the services revise their estimates and justification material to support the President's budget before the Congress. The final budget estimates must be ready for consideration by the President, for revision and for printing, in time for presentation to the Congress within the first fifteen days of the regular session.

Adoption

The adoption phase of the budget cycle consists of hearings by the Armed Services subcommittee of the Appropriation Committee, first in the House and then in the Senate. The bulk of the testimony consists of presentations by officials of the service departments in justification of their estimates. The success in obtaining funds from the Congress is based largely upon the ability of those testifying to present concise and logical justifications in support of the department's estimates; presuming, of course, that the programs are sound. The method of presentation is often of equal or even more importance than the format of the justifications. This requires much preparation and ingenuity by the persons concerned. Lengthy presentations prejudice the estimates, while incomplete ones leave doubt which may

result in unwarranted budget reductions. Hearings before the appropriations subcommittees provide a valuable chance for face to face talk between members of Congress and officials of the departments.

House of Representatives

The House Armed Services Subcommittee reports the bill, as proposed, to the full Appropriations Committee. The Appropriations Committee reviews the proposed bill. Upon adoption by the committee the bill is introduced in the House. After general debate the House votes on the bill as amended. The bill is then transmitted to the Senate, where it is referred to the Committee on Appropriations.

Senate

Action by the Senate Armed Services Subcommittee and by the Full Appropriations Committee is similar to that by the House Committee, except that hearings usually deal mainly with the House action and department appeals. The bill is submitted to the Senate where it is debated on the floor, and passed as amended.

Conference

With rare exceptions, a conference committee is appointed to work out adjustments between the bill as passed by the House and by the Senate. After reconsideration on the floor of each House, the bill is finally passed, enrolled, and signed by the Speaker of the House and the President of the Senate. It is then transmitted to the President, usually before the beginning of the fiscal year. Through this process the Congress controls the appropriations, which, in the final analysis, control military policy.

The President

The President must act on the whole appropriation bill. Unlike the governor in many States, he cannot veto particular items within the bill. For this reason vetoes of appropriations are extremely rare. When approved by the President or passed over his veto, the appropriation bill becomes an Act of Congress and enters the execution phase, which spans the entire fiscal year.

Execution

Just before the beginning of the fiscal year, the military departments begin another go-around similar to the estimating process, but designed for execution or management of the actual appropriations. In the Army this is called the "funding program," in the Air Force it is called the "financial plan." The Navy refers to it as apportionment and allocation requests. The process follows the same review paths that the budget estimates followed. The justification material is based, instead of on estimated requirements, upon changed conditions since the original estimates were submitted, and upon the actual or probable dollar availability. The conclusion of the process is the submission to the Bureau of the Budget of the apportionment requests.

Apportionments

Apportionments of the appropriated funds, including retention of certain reserves, are made by the Bureau of the Budget at the beginning of the fiscal year, on a quarterly basis, to the service Secretaries. They must, however, be reviewed by the Secretary of Defense, who also may limit or reserve portions of the funds. Upon the basis of the apportionments, the Comptroller, as agent for the Secretary, allocates the funds to the major commands or bureaus, who in turn make allotments to installations and operating or spending activities for obligation.

Financial Reporting

Financial reporting is, in accordance with Budget-Treasury regulations, on a monthly basis. These reports are designed to show the extent of progress in the execution of budget programs, and to disclose if the funds have been spent in keeping with approved allocations.[1] Plus this accounting system, there are Comptroller General audits, and an internal system of audits and accounts under comptrollers in each service.

The Bureau of the Budget is the watchdog of appropriations for the Nation; the General Accounting Office, the policeman. In addition each department is continually watching and checking under the guidance of a comptroller or budget officer. By practicing good management of funds during the current year, a better budget is formulated for the next year.

Three Cycles.

And so the budget cycle is completed.[2] It spans a period of nearly three years. One budget is being executed while the next one is being reviewed and adopted, while the next one is being formulated. Three separate cycles are operating at any one time.

IN CONCLUSION

The growth of the budet process advances from year to year. Congressional and Bureau of the Budget demands vary, as do the needs of the services. New and better methods are developed and used from time to time.

An understanding of the complex process of translating budget policies into programs, programs into dollars, dollars into equipment and armed forces, and accounting for these actions is of great importance. More and more, year by year, the budget becomes the "controller" of virtually all military policy. Knowledge of the process will aid you and me to do our part in furthering National Security.

[1]Some appropriation acts provide that funds be used for specific purposes. Other appropriations are for more general purposes. An appropriation for a specific object is available for that object to the exclusion of others.

[2]Actually, the budget cycle cannot be pinpointed quite so simply. The majority of appropriations are annual and must be obligated within the fiscal year. However, two additional fiscal years remain available for expenditure, after which they lapse and revert to the Treasury. Moreover, some appropriations are termed "multiple-year," which means they are available for obligation for a definite period in excess of one fiscal year. And, finally, there are "no-year" or continuing appropriations which have no time limit on the period of availability for obligation or expenditure. In general, though, we may say the execution phase of the budget cycle spans the one fiscal year.

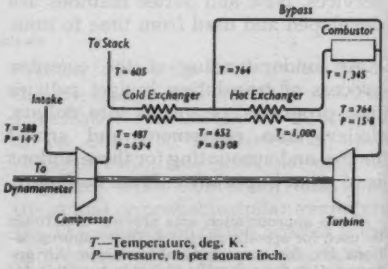
EXPERIMENTAL COAL-BURNING GAS TURBINE

ACKNOWLEDGEMENT

This is a condensed version of a paper read before the Institution of Mechanical Engineers, published in the 12 November issue of *The Engineer*. The author is Donald L. Mordell, Professor of Mechanical Engineering, McGill University, Montreal, Canada.

The only simple way of using coal to produce mechanical work has until recently been the well-known steam engine. The limitations imposed upon reciprocating-steam-engine design, if it is to be included in a locomotive, prevent the attainment of anything like a reasonable thermal efficiency, 5-7 per cent being the usual range. The development of the gas turbine was based on the use of oil or gas as fuel. However, the problems involved in its use of coal do not appear unsurmountable, and when one reflects that both the diesel engine and the steam turbine have arrived at a stage from which it is difficult to see a road leading to major advances, while the gas turbine is really just on the threshold of its development, it seems likely that the successful development of a coal-burning gas turbine might lead to a situation where coal would again be the preferred fuel for many applications.

In his Thomas Hawksley Lecture in 1951, Roxbee Cox outlined the work being undertaken in the United Kingdom on the coal-burning turbine and drew attention to the different ways of approaching the problems. One of the simplest is to adopt the exhaust-heated cycle, and this paper describes an experimental turbine operating on this cycle, which has been designed and constructed in Canada by the Gas Dynamics Laboratory, Department of Mechanical Engineering, McGill University, with the support of the Canadian Department of Mines and Technical Surveys.



T—Temperature, deg. K.
P—Pressure, lb per square inch.

Figure 1. Thermodynamic cycle diagram.

The Experimental Exhaust-Heated Engine.—In 1950 the author and his colleagues, having made fairly detailed theoretical studies (Mordell 1950; Mordell, Chant and Rogers 1950), suggested that an exhaust-heated engine would offer useful possibilities both for the generation of electrical power in relatively small units, for example, 1000-5000kW, which might be expected to be useful in Canada, particularly on the prairies, and which might also be suitable for installation in a locomotive to produce a coal-burning locomotive competitive with the diesel engine. It had been possible to obtain an obsolete aircraft engine which would provide the essential nucleus of the experimental plant it was proposed to build. The Department of Mines and Technical Surveys of the Canadian Government, which has as one of its responsibilities the development of new uses for coal, considered that that was a project which it could properly support and encourage.

The fact that it was proposed to use an existing gas turbine meant that many of the design conditions were fixed. It was decided to restrict its operation to a maximum speed of 13,600 r.p.m. and a maximum temperature of 1000 deg. K. (1340 deg. F.) as compared with the normal maximum conditions of 14,500 r.p.m. and 1100 deg. K. (1520 deg. F.). This derating cut down the maximum power to be expected from about 800 h.p. (on oil) to 500 h.p. (with coal), but it was considered essential, not only in regard to conservation of the experimental engine but also because in any event for industrial use no higher temperature than 1000 deg. K. (1340 deg. F) would be contemplated.

The basic problem was to design the heat exchangers, furnace, and ducting necessary to convert the engine to run on coal, and to lay out the plant in a manner convenient for experimental use. At the outset it was decided that in no way was the attempt going to be made to build what might be regarded as a prototype commercial unit, but that the design would be that of a research unit in which every attention was paid to the need to make many measurements, and to a probable requirement to make changes from time to time. Accordingly, plenty of space was allowed for everything and the final arrangement was that shown in the isometric view, Fig. 4. It will be seen that the basic gas turbine is mounted on a steel mezzanine floor where it is coupled up to a dynamometer with which to measure the power and an auxiliary engine to provide power for starting. Manifolds are provided which pick up the compressed air delivered by the compressor, deliver it to the heat exchangers under-

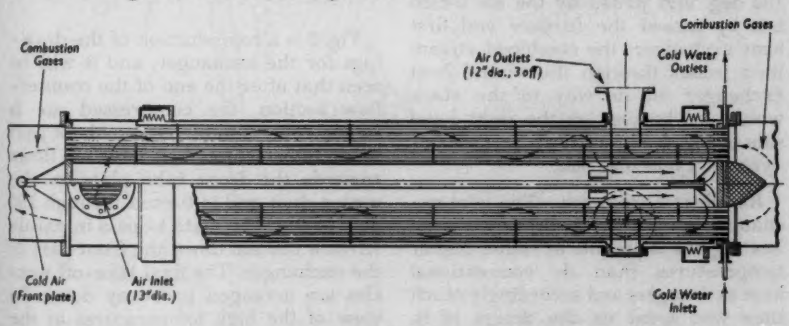


Figure 2. Arrangement of hot heat exchanger.

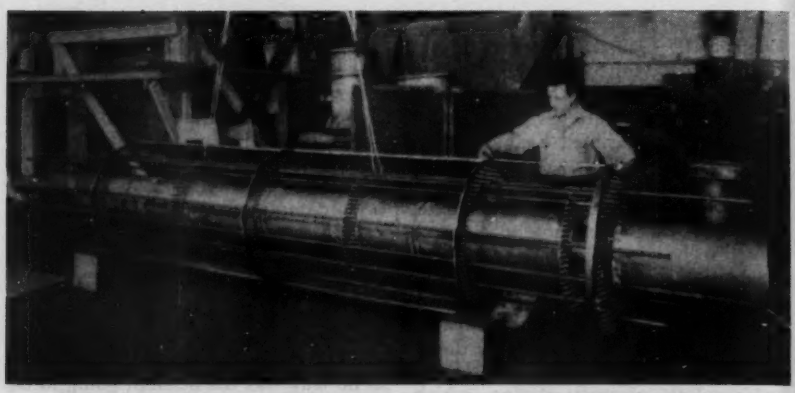


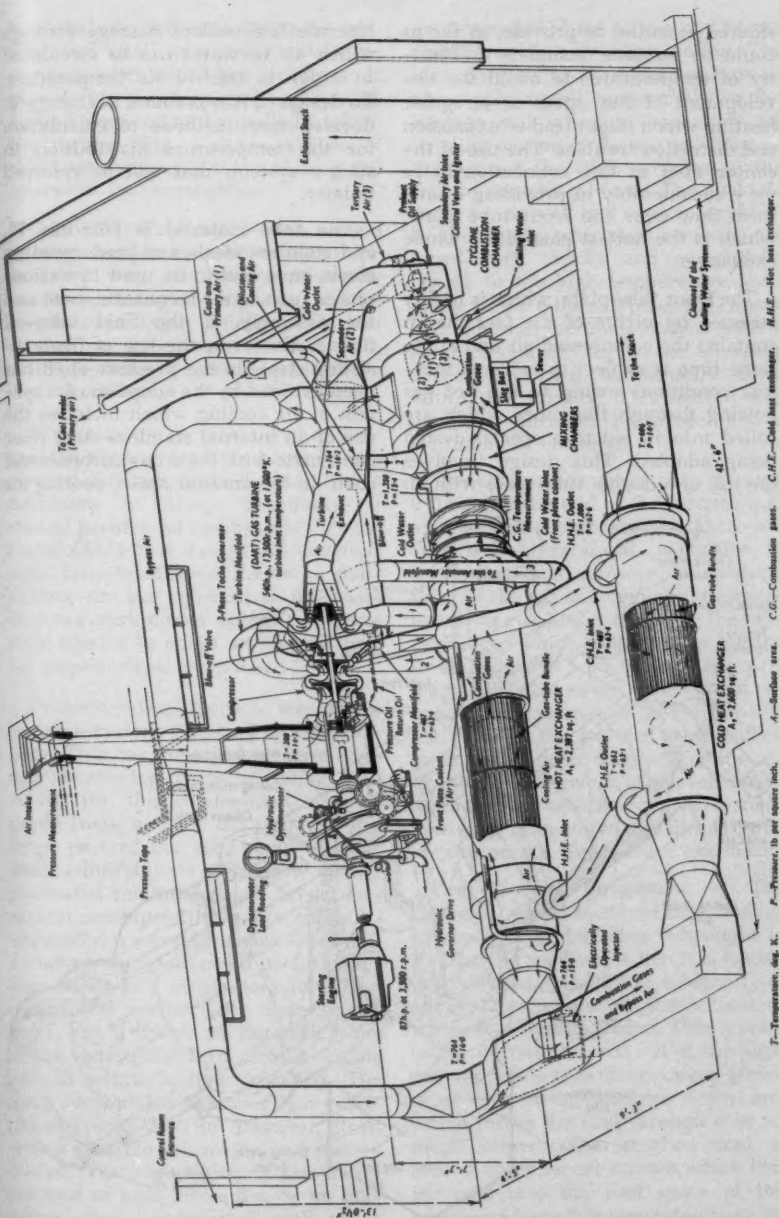
Figure 3. Tube matrix of hot heat exchanger in course of assembly.

neath and, in due course, return the externally heated air to the turbine. Behind the turbine will be seen an exhaust duct which takes the exhaust air from the turbine; some of this is by-passed in the overhead pipe to be seen in the figure, while the rest of it disappears underneath the floor to feed the furnace. On the lower floor are mounted the furnace and the two heat exchangers. Immediately beneath the turbine exhaust is the furnace, which will be described in detail later.

The hot combustion products from the furnace pass straight through the first heat exchanger to the far end, at which point they are turned through 180 deg. and joined by the air which has by-passed the furnace and first heat exchanger; the combined stream then passes through the second heat exchanger on its way to the stack which can be seen on the right-hand side of Fig. 4. Fig. 1 shows the thermodynamic cycle diagram.

Hot Heat Exchanger.—The heat exchanger which accomplishes the final heating has to operate at rather higher temperatures than do conventional heat exchangers and accordingly much time was spent on the design of it. Features of the mechanical design and related calculations have been given separately (Rogers and Chant, 1952; Rogers, 1953). The heat exchanger is designed as a mixed counterflow and parallel-flow unit. The use of counterflow is necessary in order to keep the tube area down to reasonable limits and permit the attainment of a fairly high thermal ratio, but at the hottest end the use of a parallel-flow section permits an appreciable reduction in the tube temperatures at the point where they are normally highest. The tube bundle is arranged in an annulus with a blank center space and this center space is used as the final transfer duct from the counterflow section to the parallel-flow section.

Fig. 2 is a reproduction of the drawings for the exchanger, and it will be seen that after the end of the counterflow section, the compressed air is forced down into the center blank part by an intermediate baffle. It then flows towards the front tube plate in the center duct and is turned through 180 deg. at the tube plate to pass in parallel-flow fashion down the front part of the exchanger. The final take-off nozzles are arranged part-way down. In view of the high temperatures at the hot end of the exchanger, it was con-



T—Temperature, deg. K. P—Pressure, lb per square inch. A_s—Surface area. C.G.—Combustion gases. C.H.E.—Cold heat exchanger. H.H.E.—Hot heat exchanger.
The surface area of the hot heat exchanger of 2387 square feet comprises 600 square feet of parallel-flow and 1787 square feet of counterflow unit.

Figure 4. Isometric drawing of experimental plant.

sidered essential to provide, as far as could be foreseen, complete uniformity of temperatures to avoid the development of hot spots or irregular heating which might lead to expansion and distortion troubles. The use of the center duct in this connection helps very considerably in providing a uniform flow over the front tube plate, which is the hottest part of the whole exchanger.

The front tube plate, which is highly stressed by virtue of the fact that it contains the compressed air and at the same time is subject to extreme thermal conditions owing to the hot gas flowing through the tubes which are rolled into it, led to a special design being adopted. This design involves the use of a double tube plate with an intermediate coolant passage through which air or water can be circulated in order to control its temperature. To design it, it was found necessary to develop new methods of calculation for the temperature distribution in such a system; that will be referred to later.

The tube material is Nimonic 75, and stainless steels and heat-resisting steels have had to be used in various places such as the front tube sheet and the assembly of the final take-off nozzle. However, the use of heat-resisting steels in the pressure shell has been avoided by the adoption of a system of air cooling which includes the use of an internal stainless-steel liner concentric with the outer carbon-steel shell. In the annular space, cooling air

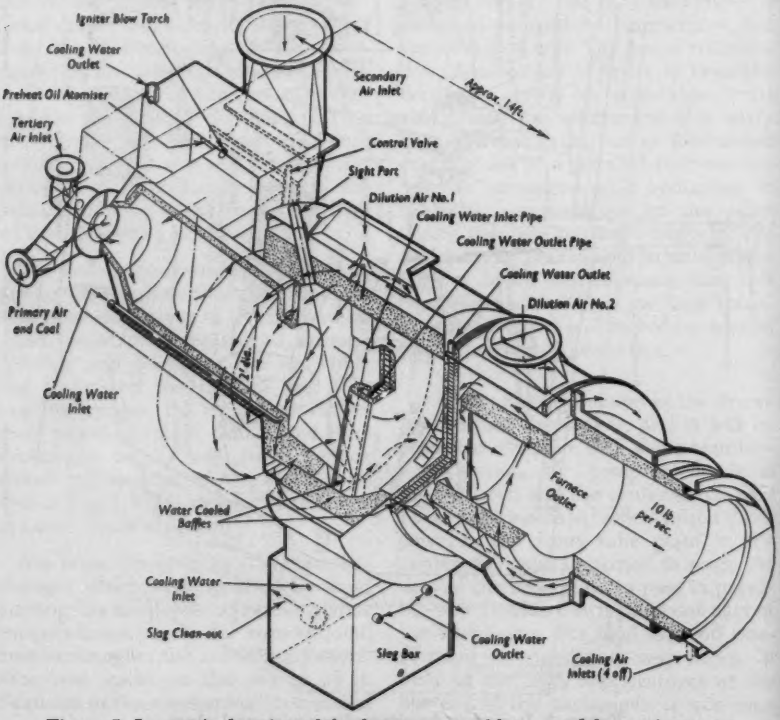


Figure 5. Isometric drawing of the furnace assembly as used for engine tests.

is passed and serves to keep the carbon steel shell at a reasonable temperature after which the cooling air is passed into the heat exchanger to be further warmed and supplied back to the turbine. Fig. 3 shows a view of this heat exchanger taken during the course of its construction.

Cold Heat Exchanger.—The second heat exchanger is quite conventional in every way, the temperatures encountered being not extreme, and its construction being wholly of carbon steel. Fixed tube sheets are used, with a simple sliding expansion joint in the shell at one end.

Manifolds. — To pick up the compressed air and feed the heated compressed air back to the turbine it was necessary to design manifolds. It should perhaps be emphasized that the manifolds, whose design and development have been one of the major difficulties, are not relevant to the coal-burning turbine as such, and were only needed to adapt an aircraft unit for experimental purposes.

Furnace.—The decision was taken to use a cyclone-slagging type of furnace. This has the advantages of having no moving parts, of being well suited for the combustion of low-grade fuels, and for the removal of a large part of the ash, while it lends itself admirably to the use of highly preheated combustion air. An experimental combustion chamber and subsequently, a second furnace was built. Although the combustion performance was raised to a satisfactory level, the mechanical performance was not too good. Fig. 5 shows an isometric view of the redesigned furnace and mixing section which is now installed. The main combustion chamber is a cylindrical vessel, 2 ft. in diameter, lined with a castable refractory, and water-cooled. The coal which is previously crushed to pass through a ⅛ in. diameter screen is injected with about its own mass of air at one end of the chamber with a swirling motion. The secondary air or the main combustion air supply is fed tangentially to the furnace and when in operation the swirling motion of the air and the coal throws out the coal particles to the wall by centrifugal force. The coal adheres to the wall and is then scrubbed by the rapidly whirling air stream and burnt very rapidly and completely. Owing to the high temperature level in the furnace the ash fuses as it forms and the wall becomes coated with a layer of molten slag whose thickness depends on the tempertaure level within the furnace. This molten slag drains out through the furnace and is continuously collected.

The combustion gases pass through a throat at the end of the furnace into a secondary chamber where there are two baffles, arranged vertically to serve the dual purpose of catching some of the ash which might otherwise be blown out, and of shielding the heat exchanger which follows from the intense radiation from a very hot primary zone. Excess air, which is not required for combustion, is fed into the hot gases in the wake of these baffles, having first been used as cooling air to cool the brickwork of the secondary mixing chamber. The whole furnace assembly is mounted on sliding runners to permit freedom for expansion.

Coal-handling Equipment. — The raw coal, which is stored in a bunker external to the building, is brought in by truck as required, when it is loaded into a hopper, which has a capacity of about 12 tons, and at the bottom of which is a screw-feeder. This screw-feeder carries the coal out of the hopper and feeds it to the crusher, which is of the swing-hammer type, and which forces the coal through a ⅛ in. mesh screen. The crushed coal is picked up by an air stream which lifts the coal into the roof space of the building where it is separated from its

carrying air and deposited in a hopper ready for use. This hopper is scale-mounted, thus permitting measurement of the rate of coal fed by noting the diminution in weight of the hopper and its contents as a function of time. The coal is fed from the hopper to the primary air-line by an air ejector which blows the coal into the primary air-line, and which takes its air either from a plant compressor or a bleed from the turbine's compressor.

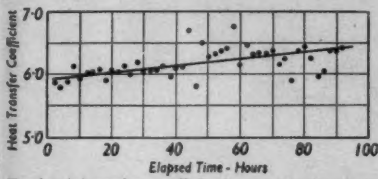
Instrumentation and Control.—Because this was a research engine and there were many problems in the heat-exchanger and furnace design on which information was scanty, very full and elaborate instrumentation has been provided. The plant is arranged so that one man has complete control of the plant, and has in his view all instruments necessary to insure safety of operation of the plant and maintenance of correct test conditions. The other more detailed measurements which are required for research purposes are indicated on panels on each side of the operator and the readings are taken by other observers. About 180 thermocouples are installed to measure important temperatures and some fifty pressure measurements are taken. In addition, there are many observations of auxiliary circuits which require watching and control. To facilitate investigation of transient conditions during warm-up and shut-down, a number of critical thermocouple readings are electronically recorded as a function of time and, in addition, transducers permitting the recording against time of engine speed, power and coal-feed rate have been developed and installed.

Assembly of the Plant.—Actual assembly of the completed installation commenced in August, 1953, following delivery of the hot heat exchanger. The problems of expansion of all the numerous elements of the plant have been taken care of largely by using suspensions rather than supports for all components so that apart from fundamental locating points the support for all members is in the form of tension rods which are free to move laterally under the influence of thermal expansion. Where this was insufficient, expansion joints have been provided in the ducting and the structure is perfectly free to expand without disturbing any of the essential alignments or opening any joints. External insulation has been applied to both heat exchangers and all the ducting and furnace, etc., in an attempt both to keep down the external heat losses and to render the test cell habitable during operation. Owing to space limitations a complete view of the plant cannot be shown, but Figs. 8, 9 and 10, give the best views possible.

PRELIMINARY EXPERIMENTAL WORK

Heat Exchanger. — Two problems that were immediately apparent in the heat-exchanger design were, first, the probable rate of fouling and, secondly, the effectiveness of the cooling arrangements for the front tube plate. Although it was intended to use a slagging type of furnace, part of the ash in the fuel has to pass through the heat-exchanger tubes, and the effect of tube fouling on the rate of heat transfer is not calculable. Accordingly, the Fuels Division constructed a test rig in which conditions of the hot exchanger were simulated in an exchanger with four 1 in. diameter tubes, 10 ft. long. This was fired with gases from a small cyclone chamber, in which provision was made to inject extra ash. Tests were made over 36-hour periods with five different coals. The ash remaining in the tubes was

found to be non-adherent and could be removed by light brushing. In no case was its amount greater than 2 per cent of the ash in the coal charged. Measurements of heat-transfer coefficients were also made, and the results of a 90-hour test are shown in Fig. 6 (reproduced from Warren and others (1952)). Although there is a considerable scatter, due in part to instrumentation difficulties, it was concluded that ash fouling should not be critical,



The heat-transfer coefficients are expressed in Centigrade heat units per hour, per square foot per degree Cent.

Figure 6. Results of heat-exchanger fouling tests.

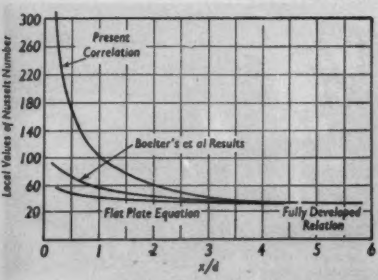


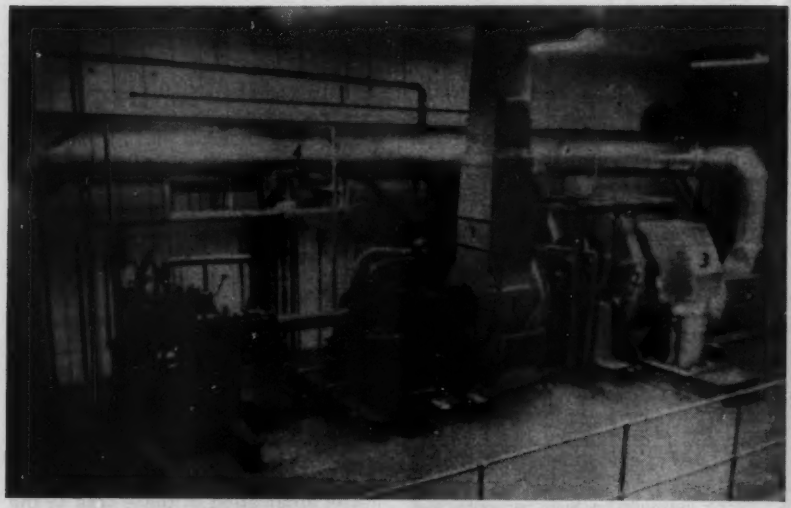
Figure 7. Heat-transfer coefficients in tube entry length.

although final conclusions can be drawn only after prolonged operation of the complete unit.

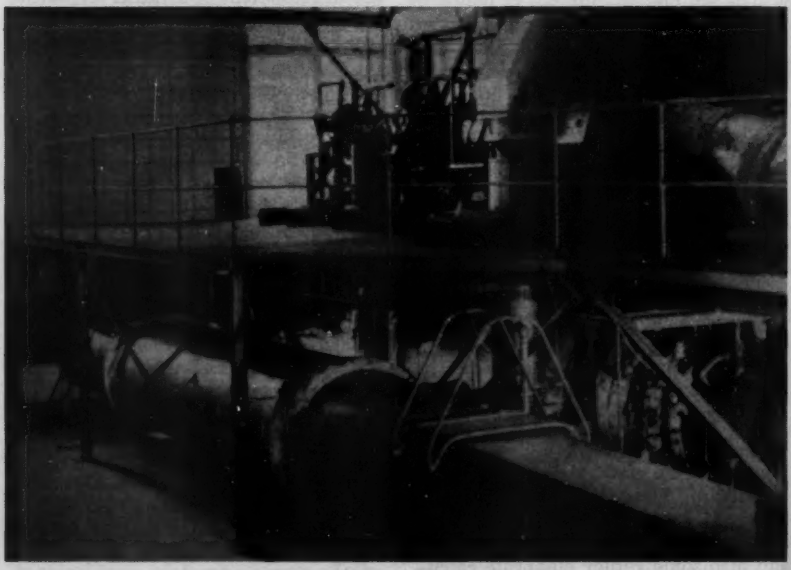
The design of the cooling system for the front tube plate demanded knowledge of the local heat-transfer coefficients in the entrance length of the tubes, before pipe flow is established and also some rather elaborate calculation of the resultant temperature distribution in the tube plate. Again a small-scale model rig was constructed and tested (Rogers, 1953). For the transfer coefficients some very interesting results were obtained, which suggested that at high temperatures existing data were not too satisfactory. Fig. 7 shows a plot of values of local heat-transfer coefficients as a function of x/d, the length/diameter ratio. It will be noted that the values are considerably higher than those of other workers and in view of the importance of this to the design, a considerable study was made. It was suspected that turbulence was a factor, but it was found that in tests at the same Reynolds number, measured values showed a trend to higher values as the absolute temperature increased. This is discussed in detail in the reference cited.

The application of these data to the determination of the temperature distribution in the tube plate required the development of a rather elaborate theory. To check this, a model of the front end of the heat exchanger was built, using seven mild steel tubes of 5/16 in. outer diameter, 20 Birmingham gauge, expanded into a ¾ in. thick mild steel tube-plate, and arranged on a 9/16 in. equiangular pitching. The cooling passage in the tube plate was ¼ in., and the tubes were fed with hot air from a gas-fired combustor. The measured temperature distribution in the plate was compared with that calculated by means of the data referred to above; some typical results are given in Fig. 11, and show a reasonable agreement. This gave confidence in the design of the full-scale exchanger. It will be observed that allowance for the variation in local values of the heat-transfer coefficient, as determined in the earlier tests (Fig. 7) makes about 10 per cent difference in the predicted values and brings them within about 10 per cent of the measured value.

Furnace.—The cyclone burner already described above appears to offer

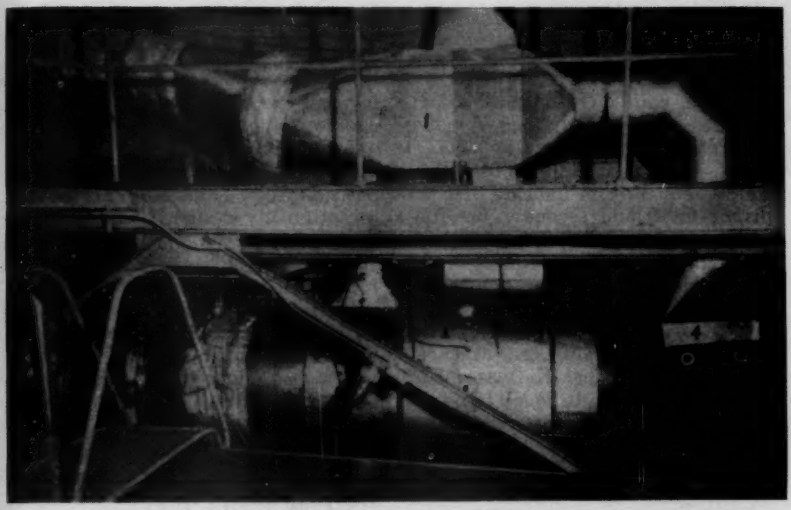


(*a*) Starting engine, dynamometer and turbine.
(1) Air-entry plenum chamber. (2) Compressor manifold. (3) Turbine manifold.
(4) By-pass-air venturi meter. (5) Turbine-exhaust header duct.



(b) The two heat exchangers.
(1) Turbine-exhaust duct. (2) Hot heat exchanger.
(3) Ducting between furnace and hot heat exchanger. (4) Cold heat exchanger.

Figures 8 and 9. The completed plant.



(c) Furnace and mixing section.
(1) Turbine-exhaust header duct. (2) First-stage mixing section.
(3) Second-stage mixing section. (4) Secondary (combustion) air entry to cyclone.
(5) Water-cooled cyclone furnace.

Figure 10. The completed plant.

the neatest solution to the actual coal-burning problem (Wilcoxson, 1947). After some initial testing, the Fuels Division built a cyclone (shown diagrammatically in Fig. 12) and ran preliminary tests. With the test facilities then available in Ottawa this could not be tested under all the necessary conditions and a similar furnace was constructed in the University laboratory, and supplied with the exhaust from the "Dart" turbine, then burning kerosene. By loading the turbine, any desired preheat temperature to the furnace could be obtained. The only difference between this set up and that intended for the full plant was that the combustion air was deficient in oxygen, having been heated by internal combustion. A program of tests was carried out. They have been reported in detail elsewhere (Mordell, Chant and Foster-Pegg, 1953) and may here be summarized by saying that they proved that good combustion could be achieved, but that heat losses were large, and that the construction was unsuitable mechanically.

The test program was interrupted before the end of the planned period as a result of a minor breakage in the engine, and it was decided to abandon both the test series and the original design of furnace mixing section, to use the results so far obtained to design the improved mixing section shown in the isometric view of the furnace (Fig. 5), and to run this for engine tests without any further rig tests.

INITIAL ENGINE TESTING

On November 20, 1953, the engine was run under its own power for the first time, with oil used as the fuel, and was subsequently run for five hours at 10,000 r.p.m., and at 900/1120 deg. K. (This convention is used here and subsequently to indicate first the turbine-inlet, and secondly the furnace-outlet, temperatures.) After inspection the plant was run again on oil for five hours on November 27th, at 12,000 r.p.m., 900/1130 deg. K., and the fuel was then turned to coal and a run of two hours on coal at 11,500 r.p.m., 870/1070 deg. K. was made. These two runs are believed to be the first runs of an exhaust-heated gas turbine on oil and coal, and it marked the completion of the first phase of the work.

The second phase, which took longer than expected, was to clear up the teething and other preliminary troubles before starting serious development and endurance running.

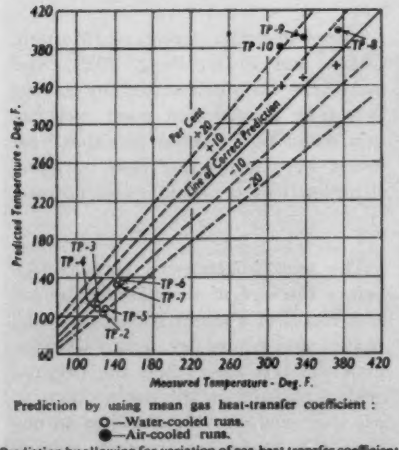


Figure 11. Comparison of measured and predicted tube-plate temperatures at different positions at one value of gas temperature (small-scale rig).

Most of the troubles experienced have been with the turbine manifolding and expansion joints and this accounts for the long time taken since a fairly complete dismantling is necessary to make any modificatinos. The basic difficulty is that the turbine, being originally designed as an aircraft engine, has a very light turbine shroud ring, and only a small load transmitted from the manifold through the expansion joints is liable to distort it and cause it to bind on the turbine blades. Curiously enough, this is a trouble which has only occurred many hours after the plant has been shut down.

In its original form the furnace behaved fairly well from the combustion viewpoint except for some difficulties with slag freezing, due largely to the relatively small amounts of coal being burnt and the low ash content of the coal used. It is necessary to ensure that there is no possibility of the coal coking immediately at the furnace entry. On two occasions, when modifications to the coal-injection system were being tried, this has happened. In these circumstances, the coal may get into the ducting and on one occasion a fire took place in the by-pass duct, which overheated the cold heat exchanger, fortunately without doing serious damage. To prevent any fur-

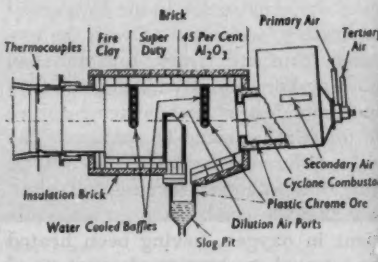


Figure 12. Furnace and mixing section as originally rig-tested.

ther occurrence a temporary modification was made to the coal-entry feed, a simple axial entry being used.

No significant troubles have yet been experienced with the heat exchangers and, after the first fifty hours, the tubes showed no sign of any ash deposition. In the hot exchanger it was found that the effects of radiation from the hot tubes on the temperature of the carbon steel outer shell had been underestimated. When the exchanger is stripped down, extra internal insulation will be applied to correct the overheating, but for the present a water-cooled pad has been applied to the critical region to avoid the delay, at a small cost in heat loss.

The air-side pressure loss was found to be higher than expected and analysis showed that the baffling was too close. This again will be rectified when the exchanger is stripped.

Although it was known that slag removal was still not perfect it was decided to give the plant an extended run to prove it mechanically: a non-stop run of fifty-seven hours was made. It was found that, when the coal-feed rate was increased beyond that used in the tests with the restricted "Dart No. 8," the temporary coal injector was not satisfactory, and blew most of the coal beyond the cyclone so that, in fact, it was mostly burning in the mixing zone. Also, as was half expected, the slag drain froze up again. The trial run was, however, continued as it was felt that it would be a severe test of the heat exchanger under the most adverse conditions that could possibly be anticipated in service. The run was completed without any troubles, the power output varying up to 250 h.p. and turbine-inlet temperatures up to 1000 deg. K.

At the conclusion of this test a total of 114 hours had been run, including nine starts and stops (two of the stops being emergency stops), and many rapid changes of load had been made so that all representative running conditions had been met. Throughout this period, although much work was done on the turbine manifolding and location, the heat exchanger received no attention whatsoever and the only maintenance on the furnace was to chip out slag. It was felt that the second phase of activities, namely, preliminary proving tests of the plant, had been accomplished.

The third phase, comprising development to ensure continuous slag removal from the furnace, satisfactory coal-feeding and long-period endurance running at incremental powers, is now in progress, and will be reported in due course.

CONCLUSIONS

Final conclusions concerning the physical possibilities of the exhaust-heated cycle must await the results of protracted operation, but from the work so far done a number of important points are obvious.

It has been demonstrated that coal can be used as a gas-turbine fuel using the exhaust-heated cycle. In spite of the large thermal capacity of the heat exchangers, the plant can be started from cold reasonably quickly. It can accept or shed load quite fast, because the load can be changed by changing turbine speed and air flow, without much change in tube temperature and, therefore, in stored heat. In emergency, it can readily be shut down. A blow-off valve, which is controlled by an overspeed governor, with a manual over-ride, has been used on the compressor delivery, and this system has proved satisfactory.

It is felt that the exhaust-heated

unit is in no way temperamental. It does not require careful nursing and maintenance and has already demonstrated its ability to run, even though combustion was far below the standards which it was known, from the rig tests, could be achieved.

The immediate program is to run about 500 hours and then strip the heat exchangers and furnace for a complete inspection. At this time the hot exchanger will be modified to rectify the shell cooling and air-side pressure loss, and the plant will then be reassembled for further continuous running.

CAPTAIN O'SHAUGHNESSY—IS YOUR BUDGET BULGING?

CAPTAIN JOHN ADRIAN HACK, USN

THE AUTHOR

is a graduate of the U.S. Naval Academy in the Class of 1935. After varied service in destroyers and submarines he received postgraduate instruction in Management Engineering at Rennselaer Polytechnic Institute. Subsequent service as Executive Officer in a Destroyer Tender, as Commanding Officer in an LSD and in his present assignment on the Staff of Commander Cruisers and Destroyers Pacific Fleet, have allowed him to observe the many applications of Industrial Management principles which help to promote economies in the Fleet. This is the fourth story concerning Captain O'Shaughnessy, the last being "Free Enterprise within the Navy—An Evaluation of Repair Ships" which appeared in the May, 1954 issue of the JOURNAL.

Elizabeth Bridget O'Shaughnessy could never be termed an expert in financial management. She had learned that, contrary to her earlier expectations, money did not grow on trees. It was delivered to her every month by a kindly postman in the form of an allotment check. From that moment until he showed up again thirty days later life was an interesting game of deciding whether shoes were more important than stockings. Why, on this particular afternoon, she happened to read the financial page Mrs. O'Shughnessy never offered a decent explanation. Perhaps she was looking for a part of the paper that no one would miss on which to dry a sweater! But the fact that she did, and clipped a diagram from it, had a profound influence upon her husband and the ships with which he worked. Since the O'Shaughnessy's have an unwritten agreement that she won't run his Navy if he won't run her house, don't breathe a word that you have heard the story of how she influenced the financial management of one small part of the naval service. She'd never let Captain O'Shaughnessy forget! Besides she might try to change a lot of other things.

Captain Michael Joseph O'Shaugnessy was new in his job on a large Force staff. Unfortunately he arrived in the middle of a year. Plans had long since been completed, moneys allocated and some expenditures made for the maintenance and repairs for which he would thereafter be responsible. In a few weeks he would be expected to submit a budget to the Fleet Commander outlining the requirements of his force in the four areas of expenditures for which the Admiral was responsible. Being inexperienced the problem of how to justify, so far in advance, large amounts of money which would be needed for overhauls, for restricted availabilities, for Ordnance alterations and Quarterly allotments, was both a challenge and a puzzle. He was overwhelmed listening

to his assistants talk about millions for this and millions for that. They told him that the Admiral commanded a force so large that it was comparable in scope of expenditures to United Air Lines Corporation. Last year the operating expenses of the force in which he now held a vital interest was approximately $182,286,000. Just how much money that was O'Shaughnessy rightly didn't know. It would buy the entire port facilities of the vast and sprawling City of San Francisco and leave him enough change to squander on a yacht or two! It was over 1.7% of the entire Navy budget! But his mind understood only little figures . . . like the size of his salary . . . or the cost of a house. Nine numerals preceded by a dollar sign were only symbolical. He could take them or leave them alone!

Each of his assistants told him the same story. He needn't be worried about the letter which was to be submitted to the Fleet Commander. They kept strict account of all the expenditures made the previous year, and during this one in progress. They would base their requirements, in each of the four categories, upon the return costs, for after all what better justification, or what better prediction could one make than to point to past costs as the yardstick upon which to base future needs? Each of his officers was an extremely conscientious lad. They reviewed every work request to insure that work was in fact justified. Requests for augmentations were studied to the extent that the Supply Officer virtually cried when he granted someone's frantic appeal for funds with which to buy materials for his ship. Their books were as honest as Abraham Lincoln. Their reasoning, coupled with their attitudes, made sense. And best of all they pointed with pride to the fact that in each category they had managed to save a little money from last year's budget, and on June 30th had returned a few hundred thousand dollars in unexpended funds to the Fleet Commander.

"HOW ARE YOU DOING THIS YEAR?"

Well it was a little early to tell. But they were sure that they would get by all right again. So far they had had no trouble. After six months they had spent only half of their funds. O'Shaughnessy was impressed and satisfied with their forthright attitude and explanations. It would be fairer to say that he was satisfied until the evening on which Elizabeth taught him a few lessons regarding the meaning of a dollar!

Like you and me, O'Shaughnessy left his millions in the desk drawer after a day in the ship and went home to face figures he could understand . . . those which came on bills from department stores, meat markets and gasoline companies. Back in the thirties when Mike and Liz were married they had smiled when the priest came to the line "for richer, for poorer." Everyone knew that you'd never be rich in the Navy. Oh life in Honolulu had been a gay one on their $315 a month. Elizabeth had been a very competent manager. Every month after the bills were paid, she always had a little left to put away in the bank. "For a rainy day," she'd say, knowing full well that rain would never fall into their serene life. They went everywhere and did everything!

But something had happened to her. Mike couldn't understand it. His salary after taxes had grown to $760 a month. Twice as much as his father had ever made! Yet every month they were going into the hole a little deeper, or so he thought. He had borrowed money to get his family across country the last time they moved. Even after

that was paid off, Elizabeth wasn't holding down the expenses as she should! For although they had over twice as much money, they went nowhere, did nothing, and served nothing!

"The trouble with you and the kids, is that you can't be content unless you're in a store spending money!"

Captain O'Shaughnessy! You should never have said that. Not to that little spitfire *you* married. Or perhaps it was lucky that you did, for you got a lesson in practical economics that was to get you out of the clouds and down to reality on the ship. Yesterday's dollars are historical, not predictions of things to come. They have to be related to something more stable and more tangible!

"So I'm not a manager! I'm just a little flippity spendthrift running around town all day throwing away your hard earned dollars! Well, MISTER O'Shaughnessy, look at this, you . . . you . . . you overstuffed stupid oaf!"

She waved a newspaper, tried to hit him with it as a matter of fact, as she swung it up to point at a partially torn out diagram in the upper right hand corner of the financial page. O'Shaughnessy shuddered at the thought that Commander Jones, or any of the others on the staff might hear of how he sat and listened. But he knew better than to do anything else when Liz got her 110 pounds of Irish fury into action.

"When we got married you made $315 a month. Here's a chart and an article which tells what happened to all the dollars you THINK you're making now. That grand salary you bring home every month is worth exactly $407.54 in the kind of money you used to woo and win me. In 1939 we had a cute little one bedroom apartment on Waikiki. What are you living in now? A four bedroom house with three baths! Your task force has grown too, CAPTAIN O'Shaughnessy. We've got four little destroyers running in and out of here now, and believe me their food and clothes don't grow in the back yard. Come off your high horse, you ignorant irresponsible Irishman. Times have changed! Sure you make over seven hundred dollars a month now. But everyone else makes more too. I think we've done all right, living as we do with a family of six on a salary which doesn't buy much more than the one we used when we were first married. The dollars I had to pay for things last year, or the year before that, or back in 1939 just can't be compared to dollars today. Last year's costs are gone! I'm just a dumb little girl where money is concerned. All I know is that when the man comes to fix the television he charges more for his services. Meat and potatoes are higher. Gasoline, lights and the telephone . . . they all cost more! Oh Mike, please don't always be pointing to last year's costs and this year's salary. It just doesn't make sense. It isn't more dollars that's bothering you . . . it's what you can buy with them!"

Yes, Captain Michael Joseph O'Shaughnessy, you learned in a very convincing fashion that you will have to do more than point to last year's costs, in your profession, or any other, if you want to predict next year's expenses. It is more obvious to you now that if budget planning is based solely upon what was spent in the past, the budget requested will not represent what, in the light of known information, should be required. If the factors which caused the expenditures have not been incorporated into the planning, changes in these factors will pass unnoticed as they occur. Many times we unwittingly have planned for excessive budgets when costs are falling. We plan deficient budgets when costs are rising. We render imprac-

ticable any cost accounting procedures with which we may control the budget. In fact, at the various echelons of adminstration, as managers change, knowledge of the conditions which caused "last year's costs" disappear with them.

A second factor of mismanagement is introduced under the "return cost" system. Too often we think solely of the dollar and forget the basic commodity we are trying to measure. Costs in one fiscal year are incurred for specific programs under specific operating conditions. Each of the programs for which budget estimates are prepared contain items which are nonrecurrent, which are based upon numbers of specific events, or which are based upon adminstrative procedures and policies. Since return costs are historical, not forecasts of events to come, the budget planned disregards the numbers of events, the specific programs, or the change in policy we know about and substitute there for what happened in the past. The administrator is then faced with the responsibility of carrying out an assigned task, without being able to plan for the funds known to be required for the tasks. In addition those senior echelons which change the budget from that requested, do so blindly without knowing what programs are being affected . . . or change the programs without realizing the obvious necessity for also changing the budget to match.

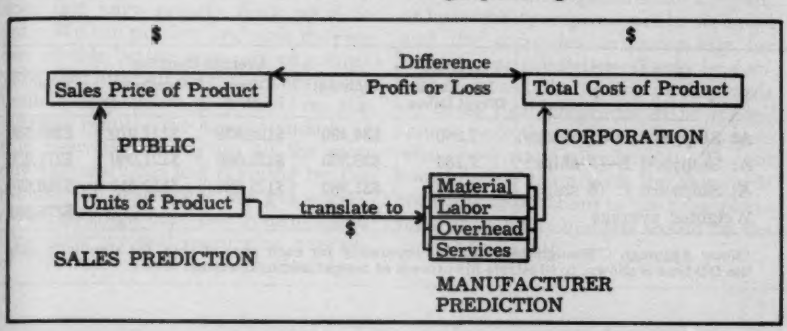
Lastly there is no active incentive inherent in the return cost concept of budget planning to reduce costs to the minimum consistent with the need. Indeed there is a slight incentive to keep budgets inflated, in order to avoid the embarrassment from changing conditions over which the administrator has no control. Because wage rates may change, material costs vary, or administrative procedures vary, the manager often loses control over the purchasing power of the dollar granted to him, without any opportunity to adjust his plans in advance. When costs are based upon what they were, rather than upon what they should be, there is little ability for any echelon to analyze costs, or to distinguish savings from inflation.

Captain O'Shaughnessy had been too chastened by Elizabeth to blindly accept his assistants' advice to submit last year's costs, and try to explain to the Admiral how these figures, in a lump sum, were valid predictions of next year's costs. He made up with his mavourneen, got down his books on financial management which had been gathering dust next to his fore and aft hat in the closet, rolled up his sleeves and went to work. He wanted a system which would be predictive of next year's shipyard overhaul costs. It would have to set a guide for the administration of repairs for an entire year, be capable of interpretation in the light of changing conditions, and above all be expressed in such a fashion that because it dealt with specific items it could be controlled.

His books told him that private industry viewed costs as a sum of the total of the *materials, direct labor, overhead,* and *services* which were required to transform raw materials into a useful product. The sales branch predicted the units of product which they could sell to the public during the coming year. From these estimates the manufacturing branch made cost predictions, computed in dollar values of materials, direct labor hours, overhead and services. The public "told" the salesmen what they would pay for the product. The manufacturer told the salesmen the cost of making the product. If the final budget thus derived was not favorable, management changed the plans until agreement was reached consistent with the profit motive. The budget then became the best forecast upon which the ac-

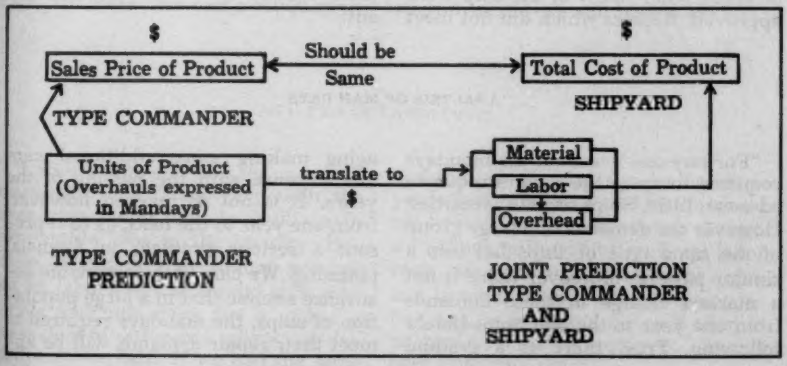
tivities of an entire corporation operated during the forthcoming year. Dollars were the common unit which measured quantities of materials and hours of labor. He did not overlook the fact that while location did not change these quantities, they had a profound effect upon the dollar measurement of them.

To assist in his analysis, O'Shaughnessy drew a sketch of industry's budget planning:



What parallel existed to help him solve his problem? Basically forces afloat told the shipyards, through a schedule of overhauls submitted to the Chief of Naval Operations, and through the types of repairs approved for accomplishment, how many of the "products" were needed. If he could advise them, in specific terms, such as man days of direct labor and quantities of material, it should not be too difficult for them to predict the costs involved. He was in essence the salesman. The shipyards was the manufacturer. If such a procedure could be devised, it was apparent that not only could he establish a reasonably accurate forecast of his requirements for next year's overhaul budget, but shipyards would be given an accurate forecast of next year's workload also. His budget and the workload planning would be based upon a common understanding. The one was no less important than the other. Strange that as the "salesman-customer" he had never been asked to supply any shipyard with such forecasts!

As a parallel he needed a plan something like this:



O'Shaughnessy had one of his assistants prepare an itemized account of each ship's yard overhaul completed during the past year. It was not difficult from the individual departure reports furnished by the shipyards to summarize the data:

	Average Man Days Direct Labor	Average Costs for Material	Direct Labor	Overhead	Total
At Shipyard A (15 ships)	7,260	$34,490	$128,430	$117,970	$280,550
At Shipyard B (5 ships)	7,180	$26,360	$125,000	$121,060	$271,420
At Shipyard C (6 ships)	6,800	$31,980	$121,380	$113,310	$266,670
Weighted average	7,100	$32,330			$275,591

(Note: Although O'Shaughnessy did this separately for each type of ship, for simplicity only the DD type is shown, to illustrate his process of budget administration)

O'Shaughnessy and his assistant studied the figures. Of themselves the numbers told him nothing. These were the historical costs of overhauling 26 destroyers in three shipyards during the last fiscal year. The Maintenance officer explained to O'Shaughnessy that in accordance with a Secretary of the Navy directive all destroyers were being treated the same, in that all repairs which were beyond the capability of forces afloat and which were essential to the combat effectiveness or operational safety of the ship were approved. Repairs which did not meet these criteria were disapproved. Only alterations which were equivalent to repairs were accomplished. By and large there was no difference in the procedures for overhauls which could vary from ship to ship.

Glancing at his chart, O'Shaughnessy now knew that he wanted for each average destroyer overhaul (the unit of product), the amount of materials required, the dollar value of the mandays required, and the dollar value of the overhead. He turned to his assistant:

ANALYSIS OF MAN DAYS

"For any one overhaul the mandays required to make the repairs requested mean little. Ships are not identities. However the demands of a large group of the same type of ships fall into a similar pattern. Moreover there is not a marked change in these demands from one year to the one immediately following. True, there is a gradual aging making more additional care and expense with the passing of the years. It is not so marked however, from one year to the next, as to represent a serious problem in financial planning. We can, with reasonable assurance assume that in a large population of ships, the mandays required to meet their repair demands will be ap-

proximately the same from one year to the next. Since shipyards do make a conscientious effort to schedule work and employ manpower efficiently we can assume that manpower efficiency does not vary greatly from yard to yard. We can predict, and note that we can do this better than any one shipyard, that after all destroyers are overhauled next year, they will, on the average require the same mandays as this year. By adding up all the man day expenditures and dividing by the number of destroyers, we get a predicted average man day requirement. Next year we will require an average of 7100 man days for each destroyer overhaul if we follow the same program as we did last year. However if we plan to add any special programs, such as title D Shipalts which are not truly alterations equivalent to a repair, or habitability improvements, we must add the man day requirements for these to our prediction. It may be necessary to ask the advice of shipyards on these new programs. It is important to note that we are the only ones who know what our plans are. By not coordinating them with the shipyards we could allow them to use false planning data. False budgets would be the inevitable result."

ANALYSIS OF MATERIAL COSTS

"As was the case with man day requirements, material requirements vary from overhaul to overhaul but are capable of being averaged. The demands of a large population of the same type of ship follow a similar pattern. Since NSA materials are standard priced throughout the Navy, costs do not vary from shipyard to shipyard. True, there are small amounts of material purchased locally, but these are so minor in quantity that we can safely disregard them. The best prediction we can make is that the average cost of overhauling one destroyer will remain the same as during the previous year. Only if the purchasing power of the dollar varies radically (you can see from this diagram which I clipped from the newspaper that it does not) or if administrative accounting changes the kinds of material we will have to pay for, will this prediction be invalid. We will assume therefore that the average material cost of overhauling one destroyer next year will be $32,330."

ANALYSIS OF LABOR COSTS

"Labor costs are *not* the same in every shipyard. They vary with the wage rate being paid to civilians in comparable jobs in the vicinity. Because of this fact we cannot average out all labor costs as we did with materials and man days, for it makes a great deal of difference *where* our destroyers overhaul. If we had the same distribution of ships to specific shipyards year after year that factor would not be important. Assignments change, sometimes quite radically. Total labor costs, being the price charged for a certain number of man days of direct labor, can be predicted for each yard in units of direct labor required . . . in this case 7100 man days:

	SHIPYARD			
	A	B	C	D
Cost of 1,000 man days at	$ 17,700	$ 17,400	$ 17,900	$ 15,800
Number of man days—7100	x 7.1	x 7.1	x 7.1	x .71
	$123,470	$122,540	$127,090	$112,180

This step is important since it is to be noted that we did not overhaul destroyers at shipyard D last year but are scheduled to do so next year. From the performance of the yard on other types we can make a prediction which we cannot get from return costs. The shipyard can advise us of these rates, or we can get them from available records."

ANALYSIS OF OVERHEAD

"Even more than the cost of direct labor, overhead varies from yard to yard. In addition to those factors which influenced the costs of materials and direct labor, the operation of the yard itself is a factor. Administrative procedures have an effect. Overhead varies with the efficiency of the yard in performing work. As we did with direct labor costs, we should initially express the overhead costs in terms of direct labor man days:

	SHIPYARD			
	A	B	C	D
Cost of 1,000 man days at	$ 16,200	$ 16,900	$ 16,700	$ 17,300
Number of man days—7100	x 7.1	x 7.1	x 7.1	x 7.1
Predicted cost of overhead	$115,020	$119,990	$118.570	$122,830

SUMMATION OF RETURN COST DATA

"Gathering these figures together the best prediction we have for the cost of the average overhaul next fiscal year would be:

	Man Days	Material	Labor	Overhead	Total
At Shipyard A	7100	$32,330	$123,470	$115,020	$270,820
At Shipyard B	7100	32,330	122,540	119,990	274,860
At Shipyard C	7100	32,330	127,090	118,570	277,990
At Shipyard D	7100	32,330	112,180	122,830	267,340
Average return cost from last year's overhauls					$275,591

"I believe," continued O'Shaughnessy, "That it is apparent now why there is no average return cost which you can apply regardless of location for the overhaul of destroyers. If you took the average cost of all last year's overhauls as a prediction, you might inflate your budget. Or you might underestimate it by large amounts. There is a spread of over $10,000 for the same overhaul in the various yards, enough to throw your budget one way or another by over a quarter of a million dollars, for the twenty seven destroyers scheduled for overhaul next year."

APPLYING THE BEST INFORMATION TO RETURN COSTS

"The predictions we worked out are valid only if the factors which determined the total costs will remain stable during the coming year. Obviously the man days required to overhaul our ships will not change radically unless we introduce a change in our policy or program. We have already agreed that we will not. We can advise the shipyards of our predicted workload. In return they can give us their best predictions of the changes to be expected in costs of material, wages and overhead."

"I called the shipyards with whom we do business and talked with the Comptrollers. All are in general agreement that Naval Industrial Fund Accounting will cause an increase in our material costs of about 5 per cent. We will have to pay for certain classes of material which have formerly been furnished "free." In addition we shall have to pay, as a direct labor charge, the cost of annual and sick leave formerly paid by the Bureau of Ships. Obviously our labor charges will increase by about 16⅔ per cent! Shipyard B advises that the wage rates of their employees are subnormal in comparison to the area wage rate. A wage survey group is expected to recommend a 5 per cent wage increase sometime in June or July. There will be other accounting changes occasioned by NIF but on the whole they will merely substitute direct labor charges for overhead. They are internal accounting procedures designed to promote better shipyard management. One will go up, the other will go down. We can ignore these in our planning."

"Obviously we cannot use last year's costs as our best prediction under these circumstances. They serve as a valuable first point of reference but nothing more than that. We know, with some degree of certainty what is going to happen at every shipyard:

	At Shipyard			
	A	B	C	D
1954 cost of material	$ 32,330	$ 32,330	$ 32,330	$ 32,330
plus 5% increase (NIF)	1,616	1,616	1,616	1,616
Predicted cost of material	$ 33,946	$ 33,946	$ 33,946	$ 33,946
1954 cost of labor	$123,470	$122,540	$127,090	$112,180
5% increase at B		6,170		
16⅔% increase (NIF)	20,980	20,832	21,605	19,071
Predicted cost of labor	$144,450	$149,542	$148,695	$131,251
1954 cost of overhead	$115,020	$119,990	$118,570	$122,830
Predicted average Overhaul Cost	$293,416	$303,478	$301,211	$288,027

"Compare those costs, based upon our best information, to the prediction of $275,591 per destroyer which you would have sent in to the Fleet Commander without such an analysis as we have just completed. Your life next year would have been a nightmare. We would have upset the plans of the shipyard, for their predicted workload couldn't have been financed by us. If we *had* to have the money, and of course we would for no one will allow ships to go un-repaired, the deficiency would inevitably have to come from the ship alteration program. On the other hand, by supplying this valuable information to the Bureau of Ships via the Fleet Commander, that Bureau will be able to submit a realistic budget request for funds in a completely justified manner. The factors of cost were so obscured in the one lump sum return cost figure, that they would have no data with which to substantiate their claims to anyone. *Always remember, a budget must be prepared in terms of the items which we must buy.* Dollars are only a medium of exchange for those items, not a description, of their quantities."

"Our budget, like that of any corporation establishes the patterns of operations for the maintenance and repair of the ships in the force throughout the fiscal year. It represents the policy established by the Admiral concerning the things we will buy, the quantities of items we will try to accomplish. In a modified form it is the *minimum* standard of performance established for the next fiscal year. In order that it may be used as such, and that you and your successor may remember as a matter of routine the various planning factors which it is based upon, we should submit it in a format which is sufficiently detailed that it may be understood. Certainly a single line 'funds required for the overhaul of destroyers . . . $15,000,000' will mean little to the Admiral, to you, and less to the officer who relieves you six months from now. On the other hand, this manner of presenting our requirements will serve as a guide to everyone concerned" O'Shaughnessy showed his assistant the budget request he had prepared. (See Figure 1).

BUDGET CONTROL

"Let's assume that we have received authorization and funds to conduct overhauls according to the plan we have submitted. The Fleet Commander has entrusted funds to us for a specific purpose. How will we know that we are in fact following our plan? Obviously we should not spend, in uncontrolled fashion, the savings which may be made by conscientious shipyard commanders, by commanding officers of ships, or even by our own efforts. You and I, and a thousand other naval officers are interested in eliminating unnecessary expenditures to the end that the overall budget may be reduced without adversely affecting our combat effectiveness. It is wasted effort, if in saving millions of dollars, we make it easy to waste the same amount somewhere else. Budget control is a vital management responsibility which insures that our efforts are directed to bettering the minimum standard imposed upon us by focussing our attentions, not upon an amount of money available for spending, but rather upon the accomplishment of *specific* authorized programs for which the money was appropriated."

"Another problem concerns us. The Admiral has the responsibility of carrying out the overhaul program, in

BUDGET REQUIREMENT FOR DD OVERHAULS
FISCAL YEAR 1955

POLICY

1. The type commander will approve for repair in naval shipyards only those items which are beyond the capabilities of forces afloat which are essential to the combat effectiveness and operational safety of a ship.

2. No special programs of alterations which are not equivalent to a repair will be accomplished.

BASIC JUSTIFICATION OF REQUIREMENTS

UNIT OVERHAUL AVERAGE COST

	AT SHIPYARD			
	A	B	C	D
1954 Cost of Material	$ 32,330	$ 32,330	$ 32,330	$ 32,330
(average of all material costs)				
plus 5% (caused by NIF)	1,616	1,616	1,616	1,616
1955 Predicted Cost	$ 33,946	$ 33,946	$ 33,946	$ 33,946
1954 Cost of Labor	$123,470	$122,540	$127,090	$112,180
(at 7100 man days)				
plus 5% at B (wage increase)		6,170		
plus 16⅔% (caused by NIF)	20,980	20,832	21,605	19,071
1955 Predicted Labor Cost	$144,450	$149,542	$148,695	$131,251
1954-1955 overhead Cost	$115,020	$119,990	$118,570	$122,830
(at 7100 man days)				
Total Predicted Overhaul	$293,416	$303,478	$301,211	$288,027

Fiscal 1955 Cost

REQUIREMENTS

	AT SHIPYARD			
	A	B	C	D
10 DD at A	$2,934,160			
5 DD at B		$1,517,390		
5 DD at C			$1,506,055	
7 DD at D				$2,016,189
TOTAL REQUIREMENTS				$7,973,794

Figure 1.

30 November 1955

EXPENDITURE REPORT FOR DD OVERHAULS

FISCAL YEAR 1955

ASSETS

Planning Limitation granted. Fiscal 1955 $7,973,794

LIABILITIES

Expenditures to date:

			Standard Budget (at 7100 man days)
4 DD at Shipyard A (average man days 7,293)			
Materials	$ 130,700		$ 135,784
Labor	577,800		577,800
Overhead	440,080		460,080
Subtotal		$1,148,580	$1,173,664
2 DD at Shipyard B (average man days 7,050)			
Materials	$ 68,000		$ 67,892
Labor	300,500		299,084
Overhead	240,950		239,980
Subtotal		$ 619,450	$ 606,956
3 DD at Shipyard D (average man days 7,025)			
Materials	$ 105,600		$ 101,838
Labor	395,201		393,753
Overhead	350,000		368,490
Subtotal		$ 850,080	$ 864,081
Total Expenditures to date		$2,618,110	$2,644,701

Reserved for future overhauls			Variation
6 DD at A @ $293,416	$1,760,496		+ 26,591
3 DD at B @ 303,478	910,434		
5 DD at C @ 301,211	1,506,055		
4 DD at D @ 288,027	1,152,108		
Total Reserved		$5,329,093	
Surplus available for return		$ 26,591	
or			
Deficit			
TOTAL LIABILITIES		$7,973,794	

Figure 2.

the manner specified, within the funds allotted to him. Obviously if another echelon has the authority to change the factors which affect the moneys required, which inflates or deflates the purchasing power of his dollar, he will want to know that fact as a matter of routine. It is our responsibility to advise him of changes in the planning factors."

Just as we formulated the budget requirements in a specific pattern, we can report our progress in carrying out the plan in a manner which will call management attention to any changes affecting it. Our success or failure, compared to the minimum standard established, can be shown if we use a corporation form of profit and loss statement. (O'Shaughnessy showed his assistant a sheet which would thereafter be used as an expenditure report. See Figure 2.)

"You will notice," explained O'Shaughnessy," that this report parallels our original budget request. Savings generated by anyone will immediately show as a surplus. Changes in the basic factors which adversely affect our planned program will cause a deficit. Both will cause an immediate inquiry on our part to find out what changed."

"In a similar fashion we can formulate accurate and specific expenditure predictions for Restricted Availabilities, for a specific ORDALT improvement program, and for Quarterly Allotment Augmentation and for ROV requirements. For each of these if we itemize the specific things we need first, we can express their cost in dollars. We won't be caught with our budgets bulging if we follow these common sense approaches to budget planning and budget control procedures!"

No, O'Shaughnessy you won't! What you have put into practice follows the mandate outlined in OPNAV Instruction 7000.2 of 5 October, 1953 to the letter:

"It is encumbent upon all persons in the naval service to whom the administration of funds is entrusted to insure that such funds are judiciously, economically, and efficiently expended. Commandants, commanders, commanding officers, and officers in charge, in accordance with naval regulations will insure that:

a. Operational and Logistic requirements are based upon sound program planning.

b. Budget estimates and requests for funds include only essential requirements to accomplish the mission at the approved level of operations.

c. All requests for funds are realistically priced.

d. Funds are administered in such a fashion as to insure accomplishment of the programs or operations for which the funds were appropriated and allotted.

e. Funds not necessary for current operations are returned to the allotting source so that savings can be realized, or more urgent requirements are financed."

O'Shaughnessy found that some of his budgets were, in fact, bulging with unneccessary money. Return costs had given his predecessors a false prediction of their requirements as conditions had changed. Others were deficient. But he had taken the first step in attacking wastes and insuring that savings were not spent on unauthorized programs. For costs were described for specific items of expenditures. They were capable of analysis; predictive; controllable!

THE TROUBLE WITH ENGINEERS

ACKNOWLEDGEMENT

This article was written by George S. Odiorne, head of the Management Services Section of Rutgers University. The article appeared in the January 1955 issue of *Harper's Magazine*.

Each spring, with the coming of the crocus, the campus of every college that can boast an engineering school undergoes its annual invasion. Recruiting agents from large industrial concerns descend on the students with attractive offers of employment; some blue-ribbon institutions receive proposals from a single company to hire the entire senior class. So important are these future engineers to industry that the professional recruiter who can charm large numbers of them into the services of his employer in advance of graduation has become more valuable, and more highly paid, than the engineers he recruits.

There are just not enough engineers in the United States to go around—not enough to meet minimum national needs at present, let alone in the future. During the past four years, in which the shortage has grown acute, the yearly supply of engineering graduates has gone steadily down. Our record sharply contrasts with that of the Soviet Union, where the annual number has been increasing—as Benjamin Fine recently pointed out in the *New York Times*—and is now two and one-half times our own. If the number of engineers is any indication, we are losing the race for technical superiority.

This is the sombre reality behind the organized — and often ludicrous — courting of engineering students: the full-page ads in the college newspapers, expense-paid tours of the company plants during winter and spring vacations, and reams of propaganda done up in the glossiest Madison Avenue style. Youngsters with two years' experience at Amalgamated Washnut appear in testimonials, looking relaxed and well fed, to endorse the company. The text suggests that industry has been stagnant, awaiting the arrival of this year's senior, who will immediately on joining Amalgamated find himself on an upward escalator to wealth and prestige.

Such is the young engineer's introduction to his profession. During his subsequent period of adjustment to industry, however, the aftereffect of these gaudy techniques may be an unpleasant one. Having overrated his value to society, he may be overly disillusioned when he finds he is less valuable than he thought. And how valuable is he? Obviously the engi-

neer is essential to the industrial scheme of things, but it not so obvious what he does or why he does it. One of the engineer's worst disillusionments can be his discovery that his function is little understood—either by the public, by his employer, or even by himself.

Not long ago, for example, there was a sharp decline in the performance of a group of electronic engineers in the New Jersey plant of a large television manufacturer. Faced with the problem of firing these scarce men, or keeping drones on the payroll, the company's personnel department decided to hold a grievance session, where at last the engineers confessed the real source of their dissatisfaction. After several years of arduous effort—and startling improvements in the complicated mechanism they were making—they had suddenly been told that the product was being dropped and that they would be assigned to other work.

These men were bitterly angry at the company, the front office, and the people they called "buckslip shufflers," and soon their complaints at being unappreciated were flying across the table. At some length a company official tried to explain that the item had become economically impracticable to produce and that "cost-regrouping imperatives" required its being dropped. Quite unconvinced, one young scientist hotly announced that he was quitting. He would look for another job, he said, "where I'll have a chance to work on pure engineering without having to worry about these *commercial* problems."

Granted that this unhappy specialist had a case; many companies do for economic or psychological reasons many things their own engineers know to be inefficient. Yet it is a good example of how an industry, crying for engineers, can fail to get the most from its own. This is the real "inefficiency," this abrasive friction that is caused when two conceptions of engineering grate against each other. I am afraid this particular engineer will discover, in the next few years, that the so-called pure technician is becoming an anachronism. And I am afraid that he will not be the only engineer to be embittered and frustrated by that discovery.

Anyone who doubts the seriousness with which industry takes the engineer shortage need only refer to the Help Wanted—Male section of any large metropolitan newspaper. An informal check I have made of the Sunday *New York Times*, off and on over an extended period, has generally revealed about fifteen columns among the fifty-odd in the classified section to be ads for engineers. This tops even the shortage of salesmen, who rank second with about eleven columns.

Numerous proposals have been made to remedy this situation, most of them by enlarging the supply of engineering manpower. Some have suggested study of the obstacles that turn students away from engineering early in their education. General Leslie R. Groves, the military engineer who ran the wartime atomic-bomb project, has even argued that "failure to teach the fundamentals of arithmetic" is the major cause of trouble and that restoration of corporal punishment in the classroom is the way to remove it. Since the time it takes to train an engineer is so long, however, these solutions can have no immediate effect. Rarely do the most enlightened discussions—including that of the late Dr. Karl T. Compton of MIT, in an issue of the *Scientific American* devoted to the human resources of the United States—raise the question we ought to ask, which is *how to use effectively the engineers we already have.*

The National Society of Professional Engineers is a notable exception, for a study it has made indicates the seri-

ous possibility that we are now wasting our most scarce and expensive manpower. Assuming this is true, the solution would appear to be simple: study what engineers do, identify the non-engineering portions of it, and solve the engineering shortage by eliminating them. Unfortunately this is not so easy as it sounds, for in first asking what an engineer is we will encounter conflicting views.

One is the engineer as society sees him—which is anyone who has accumulated technical knowledge above the workman stage, a definition that could easily include many salesmen and accountants. Second, there is the theoretical scientist's version of the engineer—which pictures him as a watered-down physicist, chemist, or mathematician; a sort of hairy-chested scientist-gone-wrong, who strides aggressively around the factory *pretending* to be a scientist. (Allied with this is the businessman's view of the engineer, which reflects a similar scorn.) Third, and most complicated of all, is the engineer's own view of what he is.

To look at these more closely, let us take them in order—beginnnig with the social view, or what we might oversimplify by calling the Veblenian engineer. Thorstein Veblen, the aggressively engineering-minded sociologist and economist of the early years of this century, believed that the success of industrial enterprise was not the achievement of financiers, or of "money" interests, but of the tough, "neutral" technicians — whom he thought best qualified to manage society for its own good.

"Without their continued and unremitting supervision and direction," he wrote in *The Engineers and the Price System* (1921), "the industrial system would cease to be a system at all . . . And it is obvious that so soon as they shall draw together . . . the situation [will be] ready for a self-selected, but inclusive, Soviet of technicians to take over the economic affairs of the country . . ."

WHO'S IN CHARGE HERE?

The Veblenian engineer took an unconscionable time a-dying, if he is dead yet. Shortly after the fall of Paris in 1940, for example, Miss Dorothy Thompson explained in one of her columns why Hitler was winning. "He has been fighting the war with an industrial and engineering economy," she wrote, "while the democracies have been fighting the war with a money or financial economy." Later that year, in *Harpers'*, Mr. Carl Dreher forcefully restated the same position, urging the engineers to step into the driver's seat of American business, thus "taking the heavy financial boot off the brakes and letting the productive machinery run freely."

This urgent advice went unheeded throughout the war, while the United States—under the direction of such "engineers" as a mail-order house president and a country lawyer from South Carolina turned politician—spewed forth the deluge of goods which met in a single year not only a domestic demand of a hundred billion dollars but an additional ninety-six billion for the military. In August 1944 President Roosevelt ordered the regular Census of Manufacturers moved forward a year in order to tabulate this miracle of production for posterity. Military, fiscal, and business managers—knowing little of the engineering problems involved—had demanded the impossible, and got it.

The engineering achievement was indeed phenomenal. But it was not the result of lifting "the heavy financial

boot," or of the concealed fiscal control that Veblen detested. It was brought about by the overt use of all the financial, sales, public-relations, social, psychological, political, legal (and if necessary illegal) devices for driving the economy—above all, by a torrent of money. Companies were spurred into war production by tax advantages on plant and equipment, by guaranteed profits under a system of cost-plus, and by the implicit threat of wage-stabilization and manpower reprisals if they failed to behave. Far from taking over, the "guild of engineers" eagerly knuckled down to meet the quotas set by their entrepreneurial bosses.

Despite this blooming of the economy without benefit of a central board of engineer-commissars, there are still signs of that enthusiasm for engineers which flowered some years before the war under the name of Technocracy. Senator Ralph Flanders, himself no technocrat, expressed the opinion in *Mechanical Engineering* not long ago that engineering techniques can readily be applied to many non-engineering problems. The nature of human beings, he explains, is so similar that they may be classified, arranged, and handled statistically much as the engineer runs correlations or stress analyses. He felt that even social relations and politics, which are but aggregate actions of people, were subject to sound engineering principles. Thus is Veblen kept up to date.

Concurrently, however, a vigorous debate has been raging within the ranks of engineering societies and in the pages of their journals, with one side arguing not for engineers to broaden their functions but to narrow them. Protests are made that today's engineer is being trained all wrong, and given too many grubby shop skills at the expense of scientific knowledge —which brings us to the theoretical scientist's view of the engineer. This holds that the engineer exists chiefly to convert the findings of pure research into practical applications, and therefore that the best engineer is the one most thoroughly steeped in science.

To the "pure" scientist, the ultimate use of his findings is far less important than the basic research which produced them. The newest electronic device is simply a reshaping of known principles: the latest synthetic raw material is merely an adaptation of something a chemist had long ago learned. Accordingly, the engineer who does the adapting can be only a subordinate on the ladder of science, an intellectual huckster a few stages above the Fuller Brush man but no different in kind.

That this attitude exasperates the engineers is understandable, but its worst effect is on their attitude toward themselves. Guiltily half-convinced of its validity, some engineers seek to isolate themselves by a similar snobbery from the other end of the scale—where lie such unscientific groups as the psychologists, economists, sales managers, and public-relations counselors. More often than we can afford, this brings about disastrous consequences to research, such as those which overtook the television concern in New Jersey.

Yet, at the same time, from this other end itself, the hapless engineer encounters as much disdain from the "pure" businessman as he gets from "pure" scientists. He is by no means as lavishly paid as his scarcity might lead you to suppose, and even within industries of a highly technical nature his prestige may be far lower than that of the most junior executive. Commenting on a *Fortune* article which stated that the ratio of engineers to non-engineers had risen, the engineering vice president of a large electrical company wrote as follows:

This results not from an increase in the proportion of engineering work but rather from the fact that engineers, as relatively cheap help, are now used for so many other activities than those for which they were trained. Anyhow, there is a general assumption that you can make more money being a manager. This has gone so far in my company that all engineers in supervisory positions are designated "managers of engineering." If the engineers, instead, were valued highly enough to be provided with secretarial service, draftsmen, technical assistance, skilled mechanics, production chasers, etc., sufficient to free them for the job which they alone can do, then I am sure it would be found not only that they could turn out more and better work but that the number of young men taking engineering training would rise in proportion to the visible rewards . . .

This engineer's personal plaint brings us closer to the crux of the matter—the demand on engineers for what they often regard as "non-engineering" work. Yet getting other people to do these jobs is not the whole solution, for it means accepting at face value the engineer's view of himself—a view that is not always as clear-cut or as realistic as the engineer himself may think.

Early in his training, the budding engineer is usually given a definition of his objective—to understand the principles of science in order to apply them to the use of Man. It is a challenging conception, implying the mission of this one profession to sustain the industrial world through its special power to convert abstract and impractical ideas into useful and beautiful objects. It demands much in the way of imagination, energy, and creativeness. Psychologically, it offers one of the most satisfying of careers, with a sense of adequacy and balance that is often lacking in other occupations. Yet these are its potentialities rather than its precise condition today; and the contract — in the light of current "shortage"—raises essential questions about the engineer's role, and his long-range status in modern society.

THE "ENGINEERING MIND"

If you ask the graduate of an engineering college what an engineer is, he will probably tell you that an engineer is the graduate of an engineering college. He and his fellow degree-holders see themselves as the "real" members of the profession, as opposed to the hybrids and parasites who cling about the fringes. The degree-holders compose the influential societies, which in turn have a large influence on the engineering colleges; they make up the voice of engineering.

Unfortunately, it is from these men that the greatest pressure comes for the isolation of engineering from both science and business. Confident that the engineering curriculum is a thing of enduring and beautiful perfection, they attribute to the engineering graduate alone that set of mental habits called the "engineering mind"—a tool so versatile and unique that it confers a virtual monopoly over logical processes to its possessor.

In any society that keeps careers open to all, each professional group has the delicate task of maintainnig standards without becoming an exclusive club; the basic demands on engineers will always be that their bridges and buildings stand up, but the idea of any profession as a closed corporation is inevitably frustrating, both to outsiders and to its members. As long as the folklore of the trade pictures the engineer as poised and self-sufficient—evenly balanced between two chasms into which he must never fall—then he will feel a rigid determination not to be tipped too far either way, lest the whole guild come crashing down. And it is such anxiety, in good part, which underlies the overt complaints about

salary, job definition, and a higher place in the industrial hierarchy. To their credit, many thoughtful engineers recognize this, and realize also that the solution lies in a voluntary evolution in engineers' ideas about themselves. Much of the "watering-down" of engineering jobs—which I would heartily endorse and prefer to call "blending"—has been brought about at engineers' initiative.

This is not a one-sided affair, however, with engineers doing all the compromising. A major responsibility for the best use of their talent lies with management—not only in organizing their jobs but most especially in the instruction it offers them when they arrive in the plant. Current practice assumes that the way to increase technical efficiency is to increase technical in-plant training. My own conclusion, after some study of the question, is exactly the opposite—that the best case can be made for more exposure of embryo engineers to economics, literature, law, psychology, history, political science, and as much purely general information as they can absorb. This is no educator's plea for the humanities but a genuine conviction on my part that no other device to increase the engineers' efficiency will work. Not only in the universities, but also in the high-powered company training programs, we continue to train them for jobs that in fact no longer exist.

For the present-day engineer, the transition from university to laboratory or factory is easily made—it just means going from one school to another. His first year is frequently spent in what amounts to a post-graduate engineering course at companv headquarters, where the general technical principles learned at college are supplemented by the specific information the company requires. It is on graduation from *this* school that the engineer finds adjustment most difficult, for it is here that he must begin the process of "unlearning." Idea by idea, he must clear his mind of "pure" engineering in order to make way for such mundane considerations as cost, marketability, consumer foibles, company folklore, union contracts, and the personality quirks of the chief engineer—in short, all the finely tooled and delicately adjusted machinery that keeps society going. Often his work may consist of a "project" in which he will have to communicate intelligently with other technicians, suppliers, customers, lawyers, advertisers, and laymen. When he is incompetent to handle these relationships his efficiency suffers, and all too often his training has given him little help.

Similar adjustment is demanded of the new engineer if his work happens to lie close to the frontiers of science, where he finds to his dismay that the questions which present themselves are not so categorical as the ones he encountered in the classroom. In fact he discovers that in the very vanguard of science, on the edge of the undiscovered, the "answers" may be as indefinite as the ones he was given in his college courses in economics, sociology, or the arts. If he is unequipped to work in this climate of uncertainty and doubt, then his efficiency suffers further. Here again a great unlearning process must take place before he will be able to plunge, with relish and confidence, into problems that permit of no definite "solution." Inevitably the successful engineer will make this adjustment, but meanwhile time and effort—his own and others'—will have been wasted.

THE SKILLED BARBARIAN

The need for engineers in the mid-twentieth century is not merely for more of them, but for more of them who can fit effectively into the non-engineering world. Attempts to force-feed the profession, or artificially to elevate its prestige, can only mean a progressive withdrawal by engineers from society's going concern. Scorn, antipathy, or indifference before the demands of bargaining, persuasion, debate, and compromise will eventually result in a loss both of status and of voice for the very men on whom a technical civilization must heavily depend. Their need is for an ability to visualize the culture in which they live—not as a collection of castes in which theirs alone is custodian of the public weal, but as a moving balance of interests that naturally conflict, intermingle, and change. They must undo the damage of an education which treats engineering as knowledge, and engineers as individuals, as though they could not be identified with the real needs and aspirations of the rest of society.

Already numerous engineering schools have turned their efforts in this direction. Among the admirable results has been increasing use of a combined plan, by which students can take three years at a liberal arts college and then transfer for the remaining two years to an engineering institution. Each of these graduate schools may associate itself with a number of colleges; as Columbia has done with forty-three, Carnegie Tech with twenty, MIT with fifteen, Rensselaer Polytech with thirteen, Case and Illinois with ten, and so on. The student receives in college enough mathematics and science to prepare him for advanced study, but at the same time he gets the humanities, arts, and social sciences that few specialist schools could possibly provide. At the end of five years, he is given two degrees—a Bachelor of both the Arts and Sciences. This, in the long run, is a more promising solution for the engineer "shortage" than any other I have seen proposed.

Clearly it is not the way to beat the Russians at the game of Who's Got the Most Engineering Graduates? But we have had enough experience with industry to know that mere numbers are not the answer. Technical society is not measured in its productivity of degree-holders, but of goods and services; and no one of its parts is more essential than the interplay of every part with every other. Most important of all, the contest for technical preeminence must not lead us into the trap of encouraging that type of technician who has been called the "skilled barbarian"—the specialist tightly fitted into his own slot and serenely indifferent to the "unscientific" turmoil in which the rest of us live. Such a luxury, in 1955, we can ill afford.

RECENT DEVELOPMENTS IN BOILING RESEARCH

PART II. PRESSURE DROP

W. H. JENS and G. LEPPERT

Biographies will be found on page 137 of the February 1955 issue of the JOURNAL at the beginning of Part I.

Mention has already been made of the intensification of interest in boiling heat transfer (15)* which has been brought about by both military and civilian development of high-performance machines such as rockets, jet engines and nuclear reactors. One of the most important aspects of this problem of heat removal by boiling of a liquid coolant is that of pressure drop along the channel in which the flowing fluid is vaporized. This situation is especially serious in high heat flux, constant heat input systems, both because of the very large pressure changes which can occur and because of the interdependence of pressure drop, flow rate and flow fraction evaporated. As will be shown in more detail below, this interdependence can lead to flow instability and burnout in parallel heated channels.

The present discussion is concerned with the change of static pressure of a flowing two-phase fluid (especially a water-steam system) in one or more closed channels with relatively high heat input. However, studies of other types of evaporating flow should perhaps be mentioned in passing. For example, in connection with steam trap condensate drain lines, a considerable amount of work has been done on the adiabatic or nearly adiabatic flow of boiling water through pipes (1,3,6,8, 20), nozzles (14,27,31) and orifices (2,5,33). It is clear that if a flowing liquid is at saturation temperature when it enters a pipeline, the normal friction pressure drop must result in evaporation of part of the liquid if equilibrium between the phases is to be maintained. In adiabatic flow, the latent heat is supplied from the thermal energy of the liquid, so that the temperature tends to decrease as the pressure decreases and successive fractions are vaporized.

A useful classification of two-phase flow mechanisms in horizontal tubes has been made by Bergelin and Gazley (4):

a. Bubbling flow, in which vapor bubbles flow along the top of the pipe.

*Numbers in parentheses refer to similarly numbered citations in bibliography.

b. Stratified flow, in which a smooth interface exists between the liquid in the bottom of the pipe and the vapor flowing along the top.
c. Wave flow, similar to stratified flow except the interface is disturbed by waves.
d. Slugging flow, characterized by "slugs" of liquid and vapor, most of which occupy the entire flow cross-section, at least during part of the time of their travel through the tube.
e. Annular flow, in which the vapor flows through the center of the pipe and the liquid forms an annulus between the vapor core and the pipe wall.
f. Homogeneous flow (referred to as "fog flow" by Martinelli and Nelson (26)), which may be regarded as a special case of annular flow.

Observations by the authors (16,18) of flow at the exits of horizontal, vertical and inclined channels of both round and rectangular cross-section, with relatively high heat fluxes (greater than about 50,000 B/(hr)(sq ft)) and with forced convection have led to the conclusion that for such systems the flow does not fall conveniently into any of the above classifications. Sometimes the appearance of these flows seems to approach the homogeneous, but there is always evidence of relative velocity between the phases as well as a pronounced tendency toward periodic unsteadiness, as evidenced either by slugging or by bursts of a high-velocity phase, apparently vapor, passing through the flowing mixture of liquid droplets and vapor.

THE EQUAL-VELOCITY ANALYSIS

Most of the studies referred to above (1,2,3,5,6,8,14,27,31,33) were analyzed with the assumption that the water and steam were distributed uniformly over the cross-section and that the relative velocity between the two phases was zero. A notable exception was the paper by Linning (20), whose analysis acknowledged "slippage" between phases. His experiment was arranged so he could measure the momentum of the steam-water mixture leaving the test section with the result that the relative velocity could be calculated.

It is useful to develop the flow equations which describe the case of equal velocities of the liquid and vapor phases. Consider the physical model of a horizontal heated tube shown in Figure 1, with saturated liquid entering at the left and with a steam-water mixture leaving at the right. The following assumptions will be made for the equal-velocity analysis:

a. Physical equilibrium between liquid and vapor phases prevails throughout. Actually, there is good reason to believe this assumption is not valid in many systems, but there are no data as yet which will permit analysis of a departure from equilibrium in these systems.

b. Heat input rate is uniform over the entire surface of the tube, both circumferentially and along the heated length, L_T.

c. The effect of pressure change along the tube is negligible insofar as it affects the physical properties of the fluid.

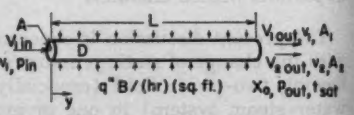


Figure 1. Physical model of forced convection boiling in a uniformly heated tube.

d. The flow is at steady state, i.e., properties at a given section do not vary with time.

e. The water and steam are distributed uniformly over the cross-section of the tube, and the relative velocity between the phases is zero. If the subscripts "1" "2" are used for the water and the steam, respectively, this assumption says that across any section, $V_1 = V_2 = V$.

The static pressure drop along such a channel as is pictured in Figure 1 may be regarded as composed of two components: one, the usual frictional pressure drop of a fluid, and the other, a pressure drop occasioned by the acceleration of the fluid as its density decreases and, consequently, its velocity increases. Write the static pressure change in the infinitesimal length, dy:

$$dp = dp_f + dp_a$$

This may be integrated to find ($p_{out} - p_{in}$), which is the quantity of interest:

$$p_{out} - p_{in} = \Delta p = \int_{y=o}^{y=L} dp_f + \int_{y=o}^{y=L} dp_a \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Under the assumptions stated, the integral involving the acceleration is readily evaluated by the application of Newton's second law, which states that the force required to accelerate the fluid from the inlet velocity to the outlet velocity is equal to the time rate of change of momentum. The result is

$$\int_{y=o}^{y=L} dp_a = \Delta p_a = \frac{G^2 v_1 x_o}{g_c}\left(\frac{v_2}{v_1} - 1\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Equation 2 simplifies to the following when $v_2 >> v_1$, the usual case when the pressure is moderate and when a significant fraction of the liquid is evaporated:

$$\Delta p_a \cong \frac{G^2 v_2 x_o}{g_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2a)$$

One approach to an evaluation of the friction term is to define a friction factor for two-phase flow which is analogous to the usual incompressible flow friction factor. For the latter,

$$\frac{dp_o}{dL} = \frac{f}{D}\frac{G^2 v_1}{2g_c} \quad \ldots\ldots\ldots (3)$$

while for two-phase flow, analogously,

$$\frac{dp_f}{dL} = \frac{f_f}{D}\frac{G^2 v_m}{2g_c} \quad \ldots\ldots\ldots (3a)$$

At this point it becomes necessary to define a mixture density

$$\rho_m = \frac{1}{v_m} = \frac{\rho_1 A_1}{A} + \frac{\rho_2 A_2}{A} \quad \ldots\ldots (4)$$

where A_1 and A_2 are the fractions of the flow area which are occupied by liquid and vapor, respectively, at any section. Equation 4 may be reduced to a more useful form by combination with the following relations which apply to any section:

$$\frac{A_2}{A} = 1 - \frac{A_1}{A}$$

$$\rho_1 A_1 V_1 = \rho_m A V (1 - x)$$

Noting that $V_1 = V$ and substituting in [4] gives the result

$$\rho_m = \frac{1}{x(v_2 - v_1) + v_1} \quad \ldots\ldots (5)$$

and when $v_2 >> v_1$

$$\rho_m \cong \frac{1}{x v_2 + v_1} \quad \ldots\ldots (5a)$$

Now it is possible to substitute and integrate in equation 3a

$$\Delta p_f = \int_{y=o}^{y=L} dp_f = \int_o^L \frac{f_f}{D} \frac{G^2}{2g_c} [x(v_2 - v_1) + v_1] \, dy \quad \ldots\ldots (6)$$

Furthermore, for uniform heating,

$$x = \frac{q'}{G A h_{fg}} y = \frac{x_o}{L} y \quad \ldots\ldots (7)$$

It will be convenient to express the two-phase pressure drop in a ratio, $\Delta p / \Delta p_o$, where Δp_o is the static pressure drop which would be calculated for the adiabatic flow of near-saturated liquid at the same mass flow rate and geometry, i.e.,

$$\Delta p_o = f \frac{L}{D} \frac{G^2 v_1}{2g_c} \quad \ldots\ldots (8)$$

Substituting into equation 6,

$$\frac{\Delta p_f}{\Delta p_o} = \frac{1}{x_o} \int_o^{x_o} \left(\frac{f_f}{f}\right) \left[x \left(\frac{v_2}{v_1} - 1\right) + 1 \right] dx \quad \ldots\ldots (9)$$

If f_f were independent of x, a rather unlikely circumstance, or if a suitable average value, f'_f, could be defined,

$$\frac{\Delta p_f}{\Delta p_o} = \frac{f_f'}{f} \left[\frac{x_o}{2} \left(\frac{v_2}{v_1} - 1\right) + 1 \right]. \quad (10)$$

The total static pressure drop may be expressed by combining equations 2,8 and 9:

$$\frac{\Delta p}{\Delta p_o} = \frac{1}{x_o} \int_0^{x_o} \left(\frac{f_f}{f}\right) \left[x \left(\frac{v_2}{v_1} - 1\right) + 1 \right] dx + \frac{2 D x_o}{f L} \left(\frac{v_2}{v_1} - 1\right) \ldots (11)$$

These equations which have been derived for the case of no relative velocity between phases will be used later in the discussion when different correlation methods are compared.

THE MARTINELLI-NELSON METHOD

It is the opinion of the authors that the most generally useful method available at the present time for predicting pressure drop during forced-circulation boiling in tubes is the one proposed by R. C. Martinelli and D. B. Nelson (26). This statement is made in spite of the fact that the method

represents essentially an extrapolation, not of experimental data for boiling flow, but of data for adiabatic flow of gas-liquid mixtures (air and water, for example). Furthermore, the prediction is for maximum and minimum limits of pressure drop which, in many practical cases, are separated by a factor of two or more.

The method consists of evaluating the ratio of actual pressure drop (in a situation such as the one depicted by Figure 1) to the all-liquid pressure drop for the same mass flow rate of liquid at near-saturation temperature as was done in equations 9 and 11. The ratio, $\Delta p_f / \Delta p_o$, is evaluated by reference to Figure 2, which Martinelli and

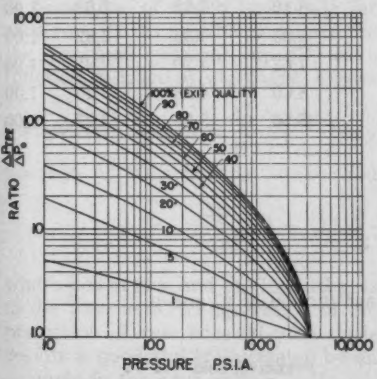


Figure 2. Ratio of frictional pressure drop in two-phase flow to liquid pressure drop as a function of exit quality and absolute pressure (26).

Nelson obtained by the extrapolation of the previously mentioned gas-liquid flow data together with a very limited amount of boiling data from the experiments of Davidson, et al. (9).

The ratio, $\Delta p_a / \Delta p_o$ is evaluated either from the "fog flow" approximation (equation 2) or by means of the equation

$$\Delta p_a = \frac{r_2 G^2}{g_c} \quad \ldots\ldots\ldots\ldots (12)$$

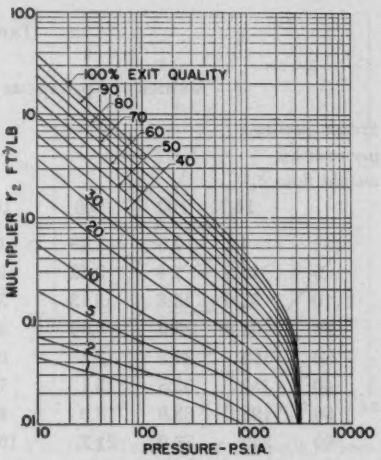


Figure 3. Multiplier r_2 for calculation of acceleration component of two-phase pressure drop (26).

where r_2 is a function of pressure and exit quality as shown in Figure 3. The latter figure approximates the condition that the steam and water at the exit are completely separated (because the data were taken from the flow of gas-liquid mixtures which were completely separated) and is supposed to give a lower limit for Δp_a just as equation 2 gives an upper limit. Tables 1 and 2 are reproduced from reference 26 and give the coordinates for Figures 2 and 3.

Relatively little experimental work has been carried out to test the validity of the Martinelli and Nelson method for predicting pressure drop with forced convection boiling in uniformly heated tubes. One of the authors (18) has reported data for the case of a horizontal stainless steel tube of ⅜-in. inside diameter with flow rates from 110 to 360 lb/(sec)(sq ft), outlet pressures from 30 to 300 psia and heat flux up to 350,000 B/(hr)(sq ft), with a maximum of about 44 per cent

TABLE 1.

Values of $\Delta p_f/\Delta p_0$ as a Function of x_0 and p

Steam quality, per cent by weight flow	*Pressure, psia*							
	14.7	100	500	1000	1500	2000	2500	3206
1	4.7	2.8	1.79	1.45	1.28	1.17	1.08	1.00
5	16.5	7.4	3.42	2.30	1.77	1.43	1.21	1.00
10	33.0	13.8	5.13	3.10	2.23	1.72	1.39	1.00
20	68.5	25.9	8.90	4.92	3.18	2.27	1.70	1.00
30	108	39.5	12.1	6.40	4.00	2.68	1.90	1.00
40	152	52.5	15.1	7.70	4.74	3.15	2.20	1.00
50	198	65.0	18.0	8.96	5.40	3.55	2.48	1.00
60	246	76.0	21.2	10.3	6.10	3.92	2.62	1.00
70	293	87.2	24.2	11.9	6.93	4.36	2.82	1.00
80	337	97	27.3	13.2	7.62	4.70	2.95	1.00
90	377	108	29.2	14.0	8.00	4.98	3.10	1.00
100	408	118	31.0	14.9	8.50	5.26	3.22	1.00

TABLE 2.

Values of Multiplier r_2 as a Function of x_0 and p

Steam quality, per cent by weight flow	*Pressure, psia*							
	14.7	100	500	1000	1500	2000	2500	3206
1	0.04	0.023	0.0130	0.0093	0.0067	0.0041	0.0021	0
5	0.16	0.068	0.0316	0.0211	0.0153	0.0100	0.0064	0
10	0.41	0.118	0.0498	0.0313	0.0227	0.0163	0.0100	0
20	1.30	0.280	0.093	0.054	0.037	0.026	0.017	0
30	2.70	0.522	0.146	0.084	0.054	0.037	0.025	0
40	4.60	0.850	0.209	0.112	0.074	0.049	0.033	0
50	7.03	1.250	0.291	0.150	0.096	0.064	0.043	0
60	9.95	1.730	0.384	0.193	0.121	0.080	0.053	0
70	13.40	2.27	0.494	0.241	0.149	0.098	0.064	0
80	17.20	2.90	0.618	0.296	0.180	0.117	0.076	0
90	21.80	3.63	0.762	0.360	0.215	0.139	0.088	0
100	26.7	4.40	0.903	0.420	0.253	0.162	0.102	0

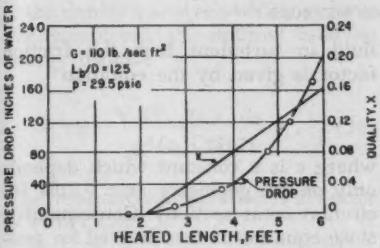


Figure 4. Typical variation of static pressure with length in forced convection boiling (18).

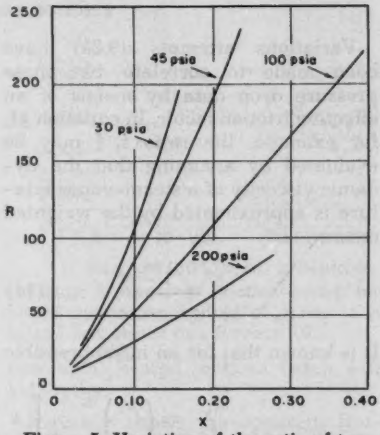


Figure 5. Variation of the ratio of two-phase static pressure gradient to liquid static pressure gradient in forced convection boiling (18).

of the flow evaporated. Boiling lengths of from two to four feet were used. Figure 4 shows the results of a typical experimental run. From graphs such as these, one of which was made for each run, it was possible to determine the pressure gradient, dp/dL, as a function of fraction vaporized. Figure 5 shows the ratio, $R = \frac{dp}{dL} \Big/ \left(\frac{dp}{dL}\right)_0$ as a function of mass fraction evaporated at the various outlet pressures used in these tests. The empirical correlation recommended for total static pressure drop along the boiling length is:

$$\frac{\Delta p}{\Delta p_o} = 1 + (1410 - 520 \log p)\, x_o^{1.17} \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

where p is in psia and the logarithm is to the base ten. The agreement of the prediction of reference 26 with these results is good and is illustrated by an example in the next section.

In another recent paper (32), pressure drop and heat transfer were studied for boiling water in forced convection downward through an annulus. The heated section consisted of an inner tube 1.08-in. outside diameter and 14 ft. long, electrically heated by direct current. The outer tube was placed concentrically to form a ⅛-in. annulus for fluid flow. Pressure drop measurements were correlated best by a modification of the results of Figure 2 used with equation 2, but the homogeneous flow approximation was fairly good even without the modification. The friction factor method discussed below (equations 14 and 11) was also investigated and found to be useful but less accurate.

Other experimental investigations which have been reported subsequently to the publication of the Martinelli and Nelson paper are those of Jens and Lottes (16) and of Weiss (35). These tests were carried out with water in vertical channels, and it was found that the results were bracketed by the upper and lower limits predicted in reference 26 in most cases. The data of Weiss generally followed the fog flow prediction, but some pressure drop values were as much as 15 per cent greater than this. McAdams (22) has discussed the data of Dengler (10), which were taken with steam-water flow upward through a 1-in., 20-ft. vertical tube.

FRICTION FACTOR METHODS

Variations attempts (9,24) have been made to correlate two-phase pressure drop data by means of an effective friction factor. In equation 11, for example, the ratio f_t/f may be evaluated by assuming that the dynamic viscosity of a steam-vapor mixture is approximated by the weighted mean:

$$\frac{1}{\mu_m} = \frac{x}{\mu_2} + \frac{1-x}{\mu_1} \quad \ldots\ldots (14)$$

It is known that for an incompressible fluid in turbulent flow the friction factor is given by the equation

$$f = \frac{c}{(DG/\mu)^{1/4}}$$

where c is a constant which depends only on the geometry ($c = 0.3164$ for circular cross section). Consequently, since equation 11 was derived for geometry and mass flow rate the same for the two-phase flow (on which Δp is based) as for the incompressible adiabetic flow (on which Δp_o is based), we may write

$$\frac{f_t}{f} = \left(\frac{\mu_1}{\mu_m}\right)^{1/4} = \left[x\left(\frac{\mu_1}{\mu_2}\right) + (1-x)\right]^{1/4} \quad \ldots\ldots (15)$$

If this ratio of f_t/f is substituted into equation 11 and a numerical integration performed* for a pressure of 100 psia (saturation pressure determines μ_1, μ_2, v_1 and v_2), one obtains a predicted value of $\Delta p/\Delta p_o$ as a function of x_o. Figure 6 shows this result and compares it with the following:

a. the empirical correlation, equation 13, obtained by Leppert (18) for boiling in a horizontal tube with L/D of 128 and heat fluxes up to 350,000 B/(hr) (sq ft). This curve is presented as the standard of comparison for the theoretical predictions.

b. the Martinelli and Nelson "fog flow" prediction, using Figure 2 and equation 2.

c. the Martinelli and Nelson prediction with slippage between phases, using Figures 2 and 3.

Comparison of these curves shows that both the friction factor method and the fog flow prediction approximate the empirical results reasonably well in this case. The latter method is more accurate in the higher ranges of outlet quality.

Among the boiling pressure drop data which have been correlated by the friction factor method and with the assumption of equal phase velocities are those of McAdams, Woods and Heroman (24) and Davidson, et al. (9). In both of these papers, instead

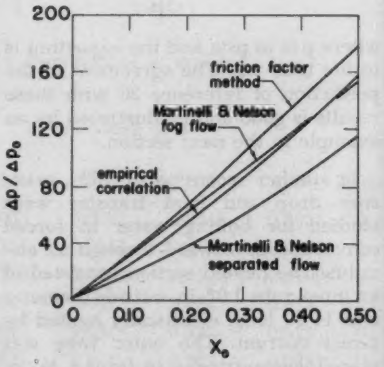


Figure 6. Comparison of various calculations of pressure gradient in forced convection boiling with empirical correlation.

*The result of this graphical integration indicates that, as one would expect, it would introduce an error of only a few per cent if an average value of f_t were used in equation 10, which can be integrated directly without graphing.

of the dynamic analysis which we have just completed, the authors used an energy balance

$$-v\,dp = \frac{V\,dV}{g_c} + \frac{f\,V^2\,dy}{2g_c D} \quad \ldots\ldots (16)$$

The result after integration is the same in either case.

The McAdams friction factor results (24) for water are plotted against the

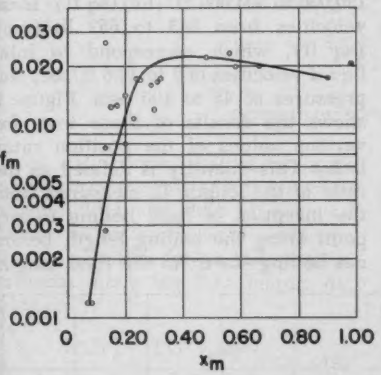


Figure 7. Apparent friction factor for forced convection boiling of water in horizontal pipes (24).

weight fraction vaporized in Figure 7. Their test apparatus consisted of 48 feet of standard 1-in. copper pipe, steam-jacketed. In the runs with water the inlet velocities ranged from 0.27 to 0.85 ft/sec, and heat fluxes ranged up to about 90,000 B/(hr)(sq ft). These apparent friction factors are not averaged over the entire heated length (48 ft) but only over the individual heated sections (each 4 ft in length).

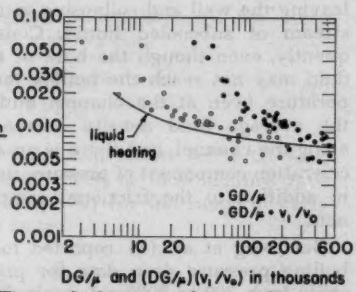


Figure 8. Apparent friction factor for forced convection boiling of water in a helical coil placed in a furnace (9).

Figure 8 shows the apparent friction factors found by Davidson, et al. plotted against the Reynolds number based on the liquid viscosity. The data are also plotted against the product of Reynolds number with specific volume ratio, v_i/v_o, where v_o is the outlet specific volume as calculated from the basic assumption of zero slippage. As may be seen from the figure, the latter representation more nearly approximates the liquid-heating friction factor line. They suggest that the specific volume ratio corrects for the effects of separation of the mixture, bubble slip, etc.

The data on which Figure 8 is based were taken in flat, spirally coiled boiler tubes placed in a furnace with one side exposed to furnace heat. Pressures were from 500 to 3300 psi, mass flow rates were from about 20 to 600 lb/(sec)(sq ft), and heat absorption was from about 20,000 to 150,000 B/(hr)(sq ft).

LOCAL BOILING PRESSURE DROP

Referring again to the physical model in Figure 1, we may consider the situation in which the liquid at the inlet is at less than saturation temperature. If the heat flux is large enough, local boiling will take place, with vapor bubbles growing and collapsing at the wall or, in some cases,

leaving the wall and collapsing in the stream of subcooled liquid. Consequently, even though the bulk of the fluid may not reach the boiling temperature even at the channel outlet, the average fluid density decreases along the channel, and there is an acceleration component of pressure drop in addition to the frictional component.

Buchberg et al. (7) reported local boiling pressure drop data for pressures from 100 to 2000 psia, velocities from 5 to 30 fps and heat fluxes up to 2,000,000 B/(hr)(sq ft) in a 0.226-in. tube 24.6 inches long. The pressure drop increases with the inception of local boiling and continues to increase with increasing heat flux and decreasing water temperature. Rohde (29) deduced the local boiling pressure gradients from these data and correlated these deduced pressure gradients by means of the following equation:

$$\left(\frac{dp}{dL}\right)_{LB} \Big/ \left(\frac{dp}{dL}\right)_{\circ} = e^{\frac{384}{p}\left(\frac{q''_{LB}}{q''_{\circ}} - 1\right)}$$

Where p is in psia

Reynolds (28) has correlated his experimental data for the static pressure gradient in forced convection local boiling. His measurements were made with distilled water flowing through an electrically heated, horizontal stainless steel tube, ⅜-in. i.d. and 6 ft long, with heat fluxes from 130,000 to 304,000 B/(hr)(sq ft); mass velocities from 343 to 652 lb/(sec)(sq ft), which correspond to inlet liquid velocities of 7 to 10.6 ft/sec; and pressures of 45 to 100 psia. Figure 9 shows the results of these tests for various values of the position ratio, L/L_T. This quantity is defined as the ratio of the length, L, measured from the inception of local boiling to any point along the boiling length before net boiling starts; to the total length,

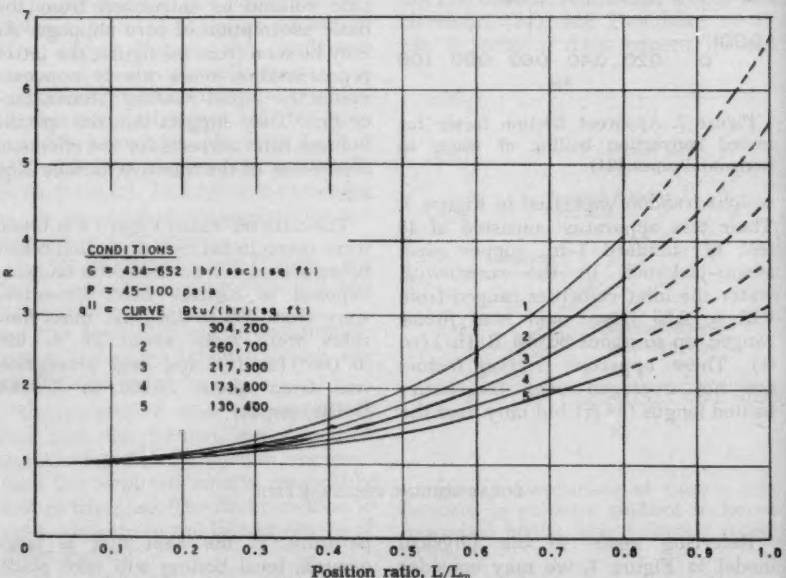


Figure 9. Variation of the Ratio of Local Boiling Static Pressure Gradient to Liquid Static Pressure Gradient in Forced Convection Boiling (28).

L_T, over which local boiling takes place (i.e., from inception of local boiling to inception of net boiling). An energy balance shows that

$$\frac{L}{L_T} = \frac{4q''L}{GDc\,(\Delta T_{sub})_o} = 1 - \frac{(\Delta T_{sub})_L}{(\Delta T_{sub})_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

Consequently, the pressure gradient ratio, R, was found to be a function of the subcooling of the liquid and the heat flux. Reynolds recommends the following expression for total static pressure drop in local boiling (over the length L) for the range of variables tested:

$$\Delta p_{LB} = \left(\frac{dp}{dL}\right)_o \frac{GDc(\Delta T_{sub})_o}{4\,a\,q''} \sinh \frac{4\,a\,q''\,L}{GDc(\Delta T_{sub})_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

$$\text{where } a = 4.6 \left)\frac{q''}{10^6}\right) + 1.2$$

CRITICAL OR SONIC FLOW RATE

It is well known that there is an upper limit to the rate at which a compressible fluid can flow in a closed channel. If we write once again the dynamic equation for an infinitesimal increment along the flow length, dy, we obtain.

$$dp + \frac{G\,d(Gv)}{g_c} + \frac{f\,G^2\,v_m dy}{2\,D\,g_c} = O. \quad \ldots\ldots\ldots\ldots\ldots\ldots (19)$$

Assume, at first, a frictionless* adiabatic expansion, i.e., an isentropic expansion, so that the maximum possible discharge rate may be found from equation 19 when $(\partial G/\partial p)_s = 0$. These considerations yield the usual relation

$$G_{max} = \sqrt{g_c \left(-\frac{\partial p}{\partial v}\right)_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

It can also be demonstrated that with adiabatic flow in a pipe of constant diameter, the critical flow rate will be reached only at the discharge of the pipe, if at all.

Woods (36) has evaluated the partial derivative in equation 20 from steam table data. Figure 10 shows his plot from which critical discharge rate based on equation 20 may be found if discharge pressure and fraction evaporated or energy content are known. As one would expect, Figure 10 does not predict G_{max} with accuracy, because it

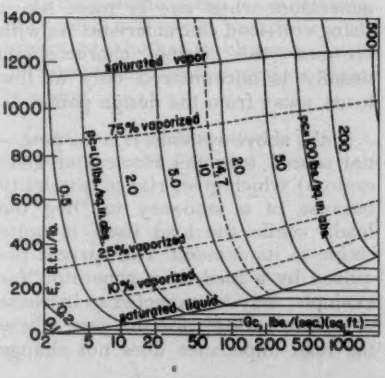


Figure 10. Maximum discharge rate, Gc, for steam-water mixtures inside pipes (36), as a function of energy content of the mixture, E, at various values of exit pressure, pc. Lines of constant quality are also shown.

*This assumption gives a somewhat greater value of maximum flow rate than would be obtained if frictional forces were admitted.

is based on the assumptions of equilibrium between phases and of equal phase velocities.

Schweppe and Foust (30) reported critical discharge rates as low as 200 to 250 lb/(sec)(sq ft) with discharge pressures of 15 to 36 psia and with a few per cent of the water flow vaporized. Stein et al. (32) analyzed their own critical flow data for downward flow of water through an annulus (described previously in this paper), as well as the data of Linning (20) and Burnell (8), and showed that the deviation of G_{max} measured experimentally from that predicted from homogeneous flow (Figure 10) is considerable, actual values of G_{max} in the neighborhood of 150 per cent or more of theoretical G_{max} being not uncommon.

STABILITY OF FLOW WITH BOILING

An unstable flow system which is well-known in engineering practice is that of parallel blowers when one or more of the machines has a rising characteristic, i.e., when it imparts a greater pressure rise to the flowing air as the flow rate increases. Most pumps and blowers have drooping characteristics, however, at least when operating near their designed flow rates. Another familiar system which may be unstable is that of parallel electric generators when one or more has a rising emf-load characteristic. As with blowers, this rising characteristic usually is encountered only at low loads, away from the design point.

In the above systems, it is the potential source (parallel blowers or generators) which gives rise to instability because of a tendency to "hog the load," while the load itself is quite stable in its demand. The current required by a load on a generator, for example, may be expected to increase with line voltage; for the case where the load impedance does not change for small changes in voltage, the load current would vary directly as the voltage. In the usual flow system, similarly, the pressure drop increases with increasing flow rate. As will be shown below, this is not necessarily the case with forced convection boiling, and an unstable system may result from the coupling of a pump with a flat or slightly drooping characteristic to a channel where a fluid is vaporized.

Returning to the physical model shown in Figure 1, we may consider the variation of the static pressure drop with the mass flow rate for a fixed outlet pressure and uniform heat flux. As has already been explained, experimental data are scarce for such systems. The experiments of Reynolds (28) and of Leppert (18) included both local boiling and net boiling pressure drop measurements, however, and utilized the same test section and flow arrangement. The following values of the pertinent variables have been chosen for an example and are tabulated below:

Tube i.d.	0.375 in.
Tube heated length	6 ft.
Outlet pressure	45 psia
Heat flux	300,000 B/(hr)(sq ft)
Inlet temperature	180°F
Horizontal flow	

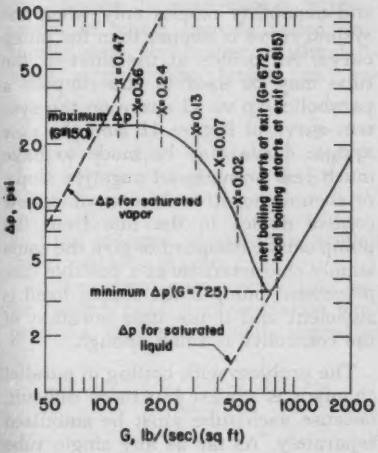


Figure 11. Variation of pressure drop with flow rate for constant heat flux, outlet pressure and inlet water temperature.

Figure 11 shows a graph of $\triangle p$ as a function of the mass flow rate, G, on log-log coordinates. For G greater than about 815 lb/(sec)(sq ft), heat transfer is entirely by forced convection, and the pressure drop is closely approximated by equation 8. At about 815 lb/(sec)(sq ft), local boiling begins at the exit, and at all lower flow rates there is some portion of the tube in local boiling. Equation 18 is used to predict the static pressure change in that portion of the tube. Figure 11 shows that $\triangle p$ reaches a minimum at about 725 lb/(sec)(sq ft).

At 672 lb/(sec)(sq ft), an energy balance shows that the bulk temperature at the outlet reaches saturation. At lower flow rates, net boiling occurs over part of the tube, and equation 13 is used for this portion. The curve is marked to show the total fraction of the flow vaporized at various flow rates, but is discontinued when about 47 per cent by weight is vaporized at the end of the heated length, because this is beyond the range of equation 13 and also because it is believed that the tube would be near failure from overheating (18). Also shown on the graph are the pressure drop characteristics for saturated liquid and for saturated steam flowing in the tube without heat input.

Some important conclusions may be drawn from the information in Figure 11. The minimum in the curve shortly after local boiling begins has already been observed; the maximum (at about 150 lb/(sec)(sq ft), in this case) is also characteristic of systems of this type, although at high heat flux burnout may occur before the maximum is reached.

Practically all of the $\triangle p$ vs. G curve which is in the boiling region is of negative slope; i.e., a decrease in G demands an increase in $\triangle p$. Figure 12 shows $\triangle p$ vs. G replotted from Figure 11, with idealized pump characteristics superimposed. The horizontal line a-a represents the characteristic of a single centrifugal pump which is to be used to supply water to the system of Figure 1. As long as the pump is not operated in parallel with other pumps, it is not important whether its characteristic is horizontal, slightly drooping, or slightly rising.

Consider operation at the point A, where no boiling occurs. If the flow

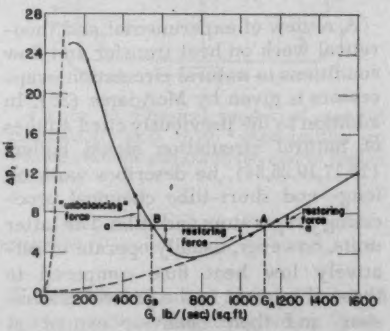


Figure 12. Stable and unstable operation of a boiling system.

tends to decrease, the pressure drop demanded by the system decreases. The available head is constant, however, so there is a net force available to accelerate the fluid and to restore the flow to G_A. Similarly, a decelerating force exists if the flow tends to increase, and the flow is again returned to G_A. For operation at point B, on the other hand, a similar argument will show that if the flow increases slightly, the existing force is not decelerating ("restoring"), but accelerating, so the flow is unstable and will "jump" to G_A. If the transient is in the direction of decreasing G, the net force is decelerating, and the flow is again unstable. In this case, however, there is no operating point on both curves to the left of G_B, since burnout is presumed to occur before the flow curve comes back down, and the flow must therefore decrease until failure occurs.

Various measures can be taken to reduce the flow instability just discussed for a single channel in forced convection boiling. A drooping pump characteristic reduces the region of instability, so that some amount of negative slope can be tolerated; if a positive displacement pump is used, the characteristic is nearly vertical, and instability results only when the system curve is steeper than the pump curve. An orifice at the inlet of the tube may be used to superimpose a parabolic Δp vs. G curve on the system curve of Figure 11, and the new system curve may be made to have much less pronounced negative slope, or even no negative slope at all. A flow control device in the line from the pump can be designed to give the same supply characteristic as a positive displacement pump if the supply head is sufficient and if the time constant of the controller is small enough.

The problem with boiling in parallel channels is similar but more difficult, because each tube must be stabilized separately. As far as any single tube is concerned, the upstream and downstream pressures (header pressures) are constant, and the "pump characteristic" is a horizontal line, as a-a in Figure 12.

Ledinegg (17) has analyzed the instability of flow in boiler tubes during natural and forced circulation, as have others (13,19,25,34), but no method has been proposed which is free of the generally questionable assumptions of no relative velocity between phases and of equilibrium between phases.

NATURAL CIRCULATION

A review of experimental and theoretical work on heat transfer and flow conditions in natural circulation evaporators is given by McAdams (23). In addition to the previously cited studies of natural circulation steam boilers (13,17,19,25,34), he describes work on long- and short-tube chemical processing evaporators and stills. The latter units, however, usually operate at relatively low heat flux compared to those of interest to the present discussion, and their behavior cannot at present be extrapolated to high-performance systems.

Harvey and Foust (12) have developed two-phase, one-dimensional flow equations and showed their application to flow in natural circulation evaporator tubes. Their work was limited to flow without apparent unsteadiness, to zero relative velocity between phases, and by other assumptions which, while necessary to their analysis, would prevent the general application of their equations.

At first glance, the problem of understanding and analyzing the behavior of a simple natural convection boiling system does not seem too diffi-

cult. Figure 13 represents a physical model in which heat is added uniformly near the bottom of the left-hand vertical pipe (riser) and removed near the top of the right-hand vertical pipe (downcomer). The governing principle may be expressed simply:

$$\oint dp = \int_a^b dp + \int_b^c dp + \int_c^d dp + \int_d^e dp + \int_e^f dp + \int_f^a dp = 0 \quad \ldots\ldots (21)$$

i.e., the integral of pressure around the closed loop is zero.

In the present case assume that water reaches point a at saturation temperature, that it is partially vaporized by the time it reaches point b, and that condensation is just completed at e. The individual integrals in equation 21 may be written in terms of changes in elevation, acceleration and friction.

$$-\int_a^b dp = \int_a^b \frac{g}{g_c}\frac{dz}{v} + \int_a^b \frac{G^2\,dv + v\,G\,dG}{g_c} + \int_a^b \frac{f\,G^2 v\,dz}{D}$$

Similar equations may be written for the remainder of the flow loop, but these will be much more difficult to solve than were those for forced convection, because now the flow rate is a variable and depends upon the average specific volume, which in turn depends upon the vaporization fraction, relative velocity between phases, etc. Because of the extraordinary complexity of the problem, no analysis has yet been published which even attempts to treat such systems without using the many simplifying assumptions already described. Consequently, it is the conclusion of the present authors that the design of natural circulation, high heat flux systems can be undertaken with safety at the present time only after extensive model tests have been conducted to determine the heat transfer and flow characteristics of the proposed designs.

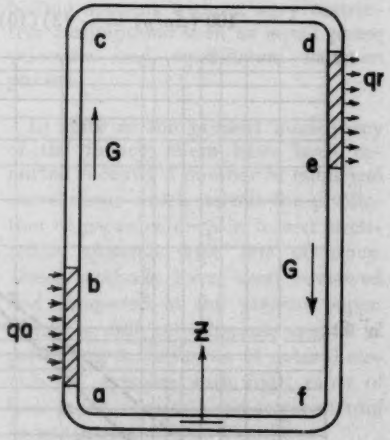


Figure 13. Physical model of natural circulation loop with vaporization in heated column and condensation in cooled column.

DENSITY VARIATION

Water-cooled and moderated nuclear reactors have been built or proposed for a number of applications, including the power plant for the U.S.S. *Nautilus* and the pressurized water reactor being designed by Westinghouse Electric Corporation as this country's (and probably the world's)

first commercial nuclear power plant. The improved cooling which would result from utilizing boiling heat transfer in such reactors has been a source of speculation for some time. However, the density changes which accompany boiling could cause rapid changes in reactivity because of variation in the number of fast neutrons which are slowed to thermal energy. Thermal neutrons are more effective than fast neutrons in producing fission and therefore increase the neutron multiplication or reactivity. Even in the neighborhood of 2000 psia, the density change with boiling is important insofar as it affects reactivity. Consequently, it is vital that the density variation of the moderator be predictable if a workable reactor design is to be developed. Prediction of the density is also important in the determination of pressure drop and circulation rate.

Gunther (11) photographed vapor bubles in a ⅛-in. thick rectangular channel heated from one side at one atmosphere pressure, from 60 to 155 F subcooling, 5 to 20 fps velocity and from 726,000 to 3,370,000 B/(hr)(sq ft) heat flux. Curves of bubble lifetime, bubble population, fraction of surface covered with bubbles and bubble radius were plotted as functions of velocity, subcooling and heat flux. Jens and Lottes (16) used these data to obtain a formula which indicates the effect of velocity, heat flux and subcooling on the change in density with local boiling:

$$100\,(\Delta\rho/\rho) = -\,(3)\,(10)^{8}\;(q''_{LB}/q''_{o})^{1.5}/V\,\Delta T^{4}{}_{sub}$$

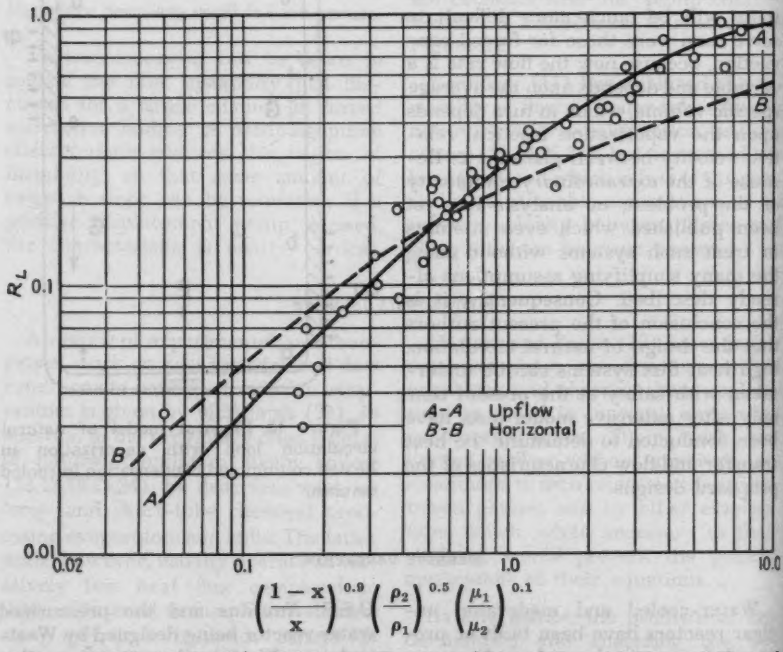


Figure 14. Variation of the Volumetric Fraction of Liquid, R_L, with Upward Flow of Steam and Water in Forced Convection (10) Compared with Data for Horizontal Flow (21).

This formula correlates the Gunther data to a factor of 2.5 or better.

Buchberg et al. (7) obtained data at presures from 500 to 2000 psia for the density of a local boiling mixture, using the change in x-ray absorption. Their data indicate no appreciable change in density (not more than one per cent) at 2000 psia for subcooling as low as 16 F and heat fluxes up to 1,000,000 B/(hr)(sq) ft). Appreciable density changes (up to several per cent) were detected for subcoolings less than 20 F at pressures of 500 and 1000 psia.

Dengler (10) measured the local volumetric fraction of liquid in forced convection boiling by adding a radioactive tracer to the water and measuring activity at various levels with a Geiger-Muller counter held outside the 1-in., 20 ft. long vertical test section. Figure 14 shows his data for the volumetric fraction of liquid, R_L, compared to the correlation of Lockhart and Martinelli (21) for isothermal, two-phase, two-component flow in horizontal pipes. Equation 4 may be used directly to find the mean density, ρ_m, for a particular system pressure and fraction evaporated.

SUMMARY

Although the present state of engineering knowledge concerning heat transfer to boiling liquids is rather advanced (15), the situation with regard to flow conditions for natural and forced convection boiling in closed channels is less satisfactory. It is known that the pressure gradient in a forced convection system after several per cent of the entering liquid has been vaporized may be hundreds of times greater than that at the entrance, where no boiling takes place. Even when the bulk temperature of the liquid is below saturation, local boiling may occur and increase the static pressure gradient several-fold. Relatively few attempts have been made to analyze the flow behavior in boiling systems without very restrictive assumptions such as equal phase velocities and equilibrium between phases.

In spite of the present inadequacy of the theory, there have been reported recently a number of empirical correlations which permit the prediction of pressure drop in forced circulation systems with fair accuracy. These methods have been reviewed and compared in the present paper. There is still no adequate means of predicting the behavior of natural circulation systems with high rates of heat input except by an experimental investigation.

NOTATION

A	Area of flow cross section, sq ft
c	Specific heat of liquid, $B/(lb_m)(F)$
D	Diameter, ft
E	Energy of mixture, initial enthalpy + heat added, B/lb_m
f	Friction factor for liquid flow
f_t	Local friction factor for two-phase flow
f'_t	Friction factor for two-phase flow, averaged over length
G	Mass flow rate, $lb_m/(hr)(sq\ ft)$ or $lb_m/(sec)(sq\ ft)$
G_{max}	Critical mass flow rate, $lb_m/(hr)(sq\ ft)$ or $lb_m/(sec)(sq\ ft)$

g_c	Dimensional constant, $(lb_m)(ft)/(lb_f)(hr)^2$
h_{fg}	Latent heat of vaporization, B/lb_m
L	Distance along tube after boiling begins, ft
L_T	Total length of tube undergoing boiling, ft
p	Pressure, psf except as noted
$\triangle p, dp$	Static pressure change, psf
$\left(\frac{dp}{dL}\right)_f$	Pressure gradient for liquid flow, psf/ft
q′	Heat transfer per unit length of channel, B/(hr)(ft)
q″	Heat flux, B/(hr)(sq ft)
q''_{LB}	Heat flux during local boiling, B/(hr)(sq ft)
q''_o	Maximum heat flux that could be obtained with forced convection cooling at same velocity, temperature and pressure and without local boiling, B/(hr)(sq ft)
R	Ratio of boiling pressure gradient to liquid pressure gradient
R_L	Volume fraction of liquid, A_1/A
r_2	Factor used in calculating acceleration pressure drop component
s	Entropy, $B/(lb_m)(°R)$
t_f	Fluid bulk temperature, °F
t_{sat}	Saturation temperature, °F
$\triangle T_{sub}$	Liquid subcooling, $(t_{sat} - t_f)$, F
$(\triangle T_{sub})_L$	Liquid subcooling at any position, L, F
$(\triangle T_{sub})_o$	Liquid subcooling where local boiling starts, F
V	Fluid velocity, fph except as noted
v	Specific volume of fluid, cu ft/lb_m
x	Mass fraction of fluid vaporized, lb_m vapor/lb_m
y	Distance from entrance of heated tube, ft
z	Distance measured vertically above datum, ft.
μ	Dynamic viscosity, $lb_m/(ft)(hr)$
ρ	Density, lb_m/cu ft

Subscripts used with pressure and pressure gradient terms:

a	Pressure drop to accelerate the fluid
f	Pressure drop to overcome friction
o	Pressure drop for liquid flow
LB	Pressure drop with local boiling

Other subscripts:

1	Refers to property of liquid phase
2	Refers to property of vapor phase
m	Refers to average property of two-phase mixture
o	Refers to property evaluated at outlet of channel (end of heated length)

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BOILING HEAT TRANSFER

ACKNOWLEDGEMENT

The need to cool rockets, jet engines, and nuclear reactors has recently brought about a great deal of emphasis on boiling heat transfer. This article, appearing in the December 1954 issue of *Mechanical Engineering*, is based on a paper presented at a meeting of the Metropolitan Section of the American Society of Mechanical Engineers. The author is W. H. Jens, Nuclear Development Associates, Inc., White Plains, N. Y.

WHY IS BOILING RESEARCH NECESSARY?

In cooling a high-performance machine such as a rocket, jet engine, or nuclear reactor we are dealing with comparatively small volumes in which are generated tremendous quantities of heat. For example, the average heat generated per unit volume in a modern boiler is 10^4 Btu/ft^3 hr, whereas in a jet engine the heat generated is 10^7 Btu/ft^3 hr. In a rocket and in a nuclear reactor it might be as great as 10^9 Btu/ft^3 hr. One method of removing this heat or of cooling the confining structure is by utilizing boiling with its high heat-transfer rates and almost constant heat-transfer surface temperatures. Heat fluxes as high as 10,000,000 Btu/ft^2 hr have been obtained experimentally, and practical designs are possible with heat fluxes as great as 2,000,000 Btu/ft^2 hr. These heat fluxes can be contrasted to the heat flux in a modern boiler of about 100,000 Btu/ft^2 hr. Both applications use boiling heat transfer but of different types.

It is the characteristic of nuclear reactors and, to a large extent, of jet engines and rockets that they are constant heat-input systems. That is, regardless of the cooling rate a constant quantity of heat is generated, and if the cooling is inadequate the surface transferring heat will fail either by melting or possibly by very rapid corrosion due to its high temperature. If the cooling were to have been stopped in the experimental apparatus transferring heat at 10,000,000 Btu/ft^2 hr the surface would have melted in a fraction of a second.

The cost of reactors, jet engines, and rockets may run as high as several millions of dollars, and although nuclear reactors and jet engines are not inherently unsafe a coolant failure could be very serious in terms of human life. These then are the immediate and obvious reasons why a great deal more must be known about boiling heat transfer.

WHY IS THIS RESEARCH SO EXPENSIVE?

Boiling heat transfer involves a change in phase from liquid to vapor. Where the viscosity, density, thermal conductivity, and specific heat of the fluid could be used to describe single-phase heat transfer, in boiling many additional properties are required. The surface tension, latent heat of vaporization, saturation temperature, density of vapor, and possible other properties of both the liquid and the vapor must now be considered. In addition to the physical properties of the vapor and liquid, the geometry and mass flow, which are known to affect single-phase heat transfer, must also be considered here. Also the character of the surface transferring heat, such as the type of metal, the roughness, and the adsorbed gas seem, under certain conditions, to affect the boiling heat-transfer results. In general, because of the large number of variables, a separate investigation is required for each combination of fluid and surface. When the conditions are unusual or extreme, which they are in many cases, the cost of the investigation is great. The time is near, however, when these separate investigations will no longer be necessary.

In most boiling investigations the determination of the heat-transfer coefficient is a small fraction of the entire amount of information required. Other items such as the maximum heat that can be transferred by the surface without overheating, the pressure drop, the stability of the boiling, the density of the fluid, and other related effects are of greater importance.

In summary, research in this field is expensive because of the complexity of the problem and the need for a wide variety of associated information.

WHAT IS THE STATUS OF BOILING RESEARCH?

The morass of terminology used to describe boiling is probably very confusing. Terms like nucleate, incipient, local, pool, film, pot, bulk, saturated, subcooled, net, forced convection are prefixes that have been attached to boiling. Many have overlapping meanings, and probably no one will agree completely to all of the meanings. In order to illustrate the various types of boiling, consider heating water in a pan on the stove. As the water is heated small gas bubbles will first form at the surface. These bubbles form because of a decrease in solubility of the gas in water with a rise in temperature. Shortly thereafter very small bubbles appear that rapidly grow and collapse at the heated surface. This is called nucleate boiling because the vapor bubbles start their growth on localized ridges or valleys in the heat-transfer surface, around small dirt particles, or around groups of gas molecules all being possible nuclei for the initiation of a bubble. The bubbles grow because the water next to the heat surface is above the saturation temperature. As the bubbles extend into water, which may be below the saturation temperature, they collapse. This type of boiling is called local boiling or subcooled boiling. When the bulk of the water is heated to its saturation temperature, bubbles detach from the heated surface and continue to grow in the bulk of the fluid. The bubbles are much larger, in many cases being merely masses of vapor. This type of boiling is called saturated, pool, pot, or net boiling. If the water had been stirred either when the temperature was below or at saturation temperature, forced-convection boiling would have been obtained. Consider now that the pan had boiled dry and that a small amount of water was then added to the hot pan. In this case drops of water would dance on the surface, being insulated from the surface by a film of

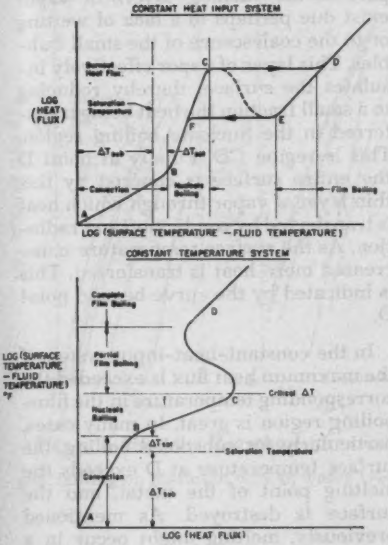

Figure 1. Major difference between constant heat input and constant surface-temperature systems.

vapor. This is called film boiling and is characterized by the film of vapor between the water and the heated surface.

Another method of classifying boiling information is by the type of heating used. The two classifications are the constant heat input and the constant surface-temperature system. The information required or obtained and the importance of the individual variables are considerably different for each case. Fig. 1 illustrates a major difference between the two systems and shows the variation of surface temperature with heat flux, which is the amount of heat flowing per unit of surface area per unit of time, for (*a*) a constant-heat-input system typified by a nuclear reactor and (*b*) a constant-temperature system typified by a heat exchanger in which heat is transferred from a liquid metal to boiling water. The curves are probably representative of forced convection, subcooled boiling, in which the fluid is below its saturation temperature at the heat-transfer surface and is being

Nomenclature

C_l = Specific heat of liquid, Btu/lb deg F
g = Acceleration of gravity
g_0 = Conversion factor, 4.17×10^8 (lb mass) ft/hr^2 (lb force)
G = Mass flow rate, lb/ft^2 hr
b_{fg} = Latent heat of vaporization, Btu/lb
m, C, C_{sc} = Constants
P = Pressure, psia
q'' = Heat flux, Btu/ft^2 hr
$q''_{B.O.}$ = Maximum or burnout heat flux, Btu/ft^2 hr
$q''_{conv.}$ = Heat flux by convection at fluid velocity, temperature and pressure Btu/ft^2 hr
V = Velocity, fps
P_{rl} = Prandtl number
pl = Density of saturated liquid, lb/ft^3
pv = Density of saturated vapor, lb/ft^3
ΔT_{sub} = Temperature difference between the saturation temperature and the fluid temperature, deg F
ΔT_{sat} = Temperature difference between the surface temperature and the saturation temperature, deg F
μl = Viscosity of saturated liquid, lb/ft hr

forced to flow past the surface. This relationship has not been completely experimentally verified. The curves are similar for boiling of a fluid at its saturation temperature and for boiling in which the flow is by natural instead of forced convection. This has been verified by experiment.

Except in the region of partial film boiling the two curves in Fig. 1 are identical, one being a mirror image of the other and rotated 90 deg. The reason the curves are drawn separately is to show the effect of a change in the independent variable. In both cases the independent variable is plotted on the ordinate and the dependent variable on the abscissa. In the case of the constant-heat-input system the independent variable is the heat flux whereas in the constant-temperature system it is the temperature difference.

Both curves are drawn for a constant pressure and constant bulk fluid temperature. At values of the surface or wall temperature below the fluid saturation temperature, heat is transferred by convection and is proportional to the temperature difference between the surface and the fluid. This is region AB. After the surface exceeds the saturation temperature of the fluid the heat flux rises rapidly with an accompanying small change in surface temperature. This region of nucleate boiling is designated as BC. Small vapor bubbles form rapidly due to the superheating of the surface and fluid adjacent to the surface. As they extend themseles into the subcooled or cooler fluid beyond the superheated film they quickly collapse.

In the case of a constant-temperature system as given by the lower curve, when the critical ΔT is exceeded, the heat-transfer rate decreases with increasing surface temperature. In this region there is probably a combination of two types of boiling. On part of the surface small bubbles still form and collapse and on another part of the surface, layers of vapor exist due perhaps to a lack of wetting or to the coalescence of the small bubbles. This layer of vapor effectively insulates the surface, thereby reducing to a small fraction the heat being transferred in the nucleate boiling region. This is region CD. Finally at point D the entire surface is covered by this thin layer of vapor through which heat is transferred by conduction and radiation. As the surface temperature is increased more heat is transferred. This is indicated by the curve beyond point D.

In the constant-heat-input system if the maximum heat flux is exceeded the corresponding temperature in the film-boiling region is great. In many cases, particularly for subcooled boiling, the surface temperature at D exceeds the melting point of the metal, and the surface is destroyed. As mentioned previously, melting might occur in a fraction of a second. If, however, the surface temperature in the film-boiling region does not exceed the melting point of the surface, then the region of film boiling behaves as previously described for the constant-temperature system. When the heat flux is reduced below the minimum point shown on the curve at point E, the surface temperature decreases to the value in the nucleate boiling region at the same heat flux, shown at point F. For a constant heat-input system the partial film-boiling region is unstable and therefore is difficult to determine.

Boiling Heat-Transfer Correlations

Numerous experiments have shown that boiling heat transfer as indicated by these two curves is not significantly dependent on the fluid velocity or the temperature of the fluid but does depend on pressure and the difference in temperature between the surface and the saturation temperature.

Surface temperatures have been correlated to ± 15 F over a wide range of conditions in a constant-heat-input

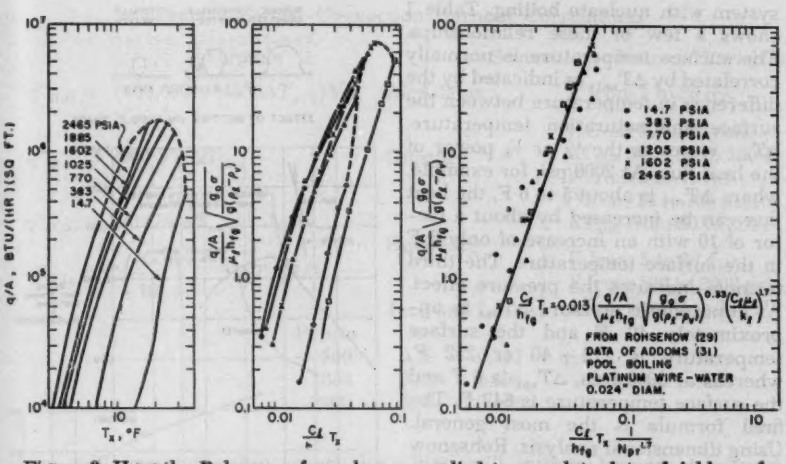

Figure 2. How the Rohsenow formula was applied to correlate data of Addoms for pool boiling on platinum wire in water (ref. 11).

TABLE 1 Boiling Heat-Transfer Correlations

Formula	Source	Range of Variables
$\Delta T_{sat} = C\,q''^{0.26}$	McAdams	Subcooled water 60 to 90 psia 5 to 20 fps
$\Delta T_{sat} = 28 - 0.012P$	Rohsenow	Subcooled water 1000 to 2000 psia 10 to 30 fps
$\Delta T_{sat} = \dfrac{60\left(\dfrac{q''}{10^6}\right)^{1/4}}{\dfrac{P}{900}}$	Jens and Lottes	Subcooled water 85 to 2500 psia 3 to 40 fps
$\dfrac{c_l\,\Delta T_{sat}}{h_{fg}} = C_{sf}\left[\dfrac{q_B''}{\mu_l h_{fg}}\sqrt{\dfrac{g_0}{g(\rho_l-\rho_v)}}\right]^{0.33}\mathrm{Pr}_l^{1.7}$ $q_B'' = q'' - q''_{conv}$	Rohsenow	Saturated pool boiling Subcooled boiling Variety of fluids 14.7 to 2000 psi 0 to 40 fps

system with nucleate boiling. Table 1 shows a few of these relationships. The surface temperature is normally correlated by ΔT_{sat}, as indicated by the difference in temperature between the surface and saturation temperature. ΔT_{sat} varies as the ⅓ or ¼ power of the heat flux. At 2000 psi, for example, where ΔT_{sat} is about 5 to 6 F, the heat flux can be increased by about a factor of 10 with an increase of only 6 F in the surface temperature. The third formula indicates the pressure effect. At atmospheric pressure ΔT_{sat} is approximately 40 F and the surface temperature is 212 + 40 or 252 F, whereas at 2000 psia, ΔT_{sat} is 6 F and the surface temperature is 642 F. The final formula is the most general. Using dimensional analysis, Rohsenow arrived at a dimensionless correlation for boiling. He defined the conventional Reynolds number in terms of the bubble diameter and frequency, the Nusselt number in terms of the bubble diameter and heat flux, and the Prandtl number in terms of the properties of the liquid. When the formula is applied to forced convection subcooled boiling a quantity termed the boiling heat flux is used. The boiling heat flux is defined as the difference between the total heat flux and the heat flux that could be transferred by convection if boiling had not occurred. Fig. 2 shows how the formula was applied to correlate the data of Addoms. In the first curve the bubble Reynolds number is plotted versus the bubble Nusselt number. It is not until the liquid Prandtl number is used that the data are correlated as shown in the last set of curves.

Rohsenow indicates that many other variables influence nucleate boiling heat transfer. As a matter of fact, he introduces an arbitrary constant to account for different fluid and surface combinations. He indicates that probably the most important variable not included in his final dimensionless

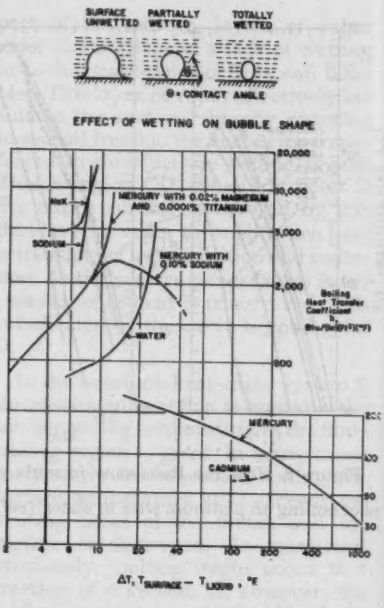

Figure 3. Comparison of experimental boiling heat-transfer coefficients for water and liquid metals (ref. 2).

equation is the average bubble contact angle. Fig. 3 shows the bubble contact angle which is a measure of the degree of wettability of the fluid upon the surface. The contact angle decreases with greater wetting and the heat transfer increases. The increased heat transfer is probably because less surface is directly covered with vapor films and because the turbulence in the film of superheated fluid is greatest with the smaller bubbles since the bubbles probably grow and collapse more rapidly. Some recent work with boiling liquid metals adds a great deal of credence to Rohsenow's postulation. The results are also shown in Fig. 3. Sodium, sodium-potassium, and mercury with additions of 0.02 per cent magnesium and 0.001 per cent titanium indicate the familiar convection and the

TABLE 2 Forced-Convection Burnout Correlations

Formula	Source	Range of Variables
$q''_{B.O.} = (400{,}000 + 4800\Delta T_{sub})V^{1/2}$	McAdams	V from 1 to 20 fps
$q''_{B.O.} = 7000\, V^{1/2}\, \Delta T_{sub}$	Gunther	P from 30 to 90 psia ΔT_{sub} from 20 to 100 F V from 5 to 40 fps P from 14 to 160 psia ΔT_{sub} from 20 to 280 F
$q''_{B.O.} = 520\, G^{1/2}\, \Delta T_{sub}^{0.2}$	Buchberg	V from 5 to 30 fps P from 500 to 2000 psia ΔT_{sub} from 3 to 160 F
$q''_{B.O} = C\left(\frac{G}{10^6}\right)^m \cdot \Delta T_{sub}^{0.22}$	Jens and Lottes	

P, psia	m	C
500	0.16	0.817
1000	0.28	0.626
2000	0.50	0.445

steep boiling relationship when the heat-transfer coefficient is plotted against the temperature difference. However, mercury, with and without 0.1 per cent sodium added, and cadmium, all of which do not wet the heat-transfer surface, apparently do not undergo nucleate boiling. It appears that a transition is made directly from the forced-convection region into the film-boiling region. These results not only verify Rohsenow's thesis but also indicate a possible mechanism to explain burnout.

In addition to the effect of wetting on boiling heat transfer there are other secondary effects. In very pure systems it is possible to superheat surfaces to very high temperatures. For example, at atmospheric pressure, liquid superheats of 76 F were obtained for pure water contained in a glass system at atmospheric pressure. Maintaining the purity of water and the cleanliness of the surface is extremely difficult and in practical designs these high superheats are seldom obtained. The surface roughness also affects boiling heat transfer. The rougher the surface the lower the temperature of the surface during boiling. Both adsorbed gas on a metal surface and dissolved gas in the fluid will initiate boiling at a lower surface temperature. As the gas is removed from the system the surface temperature will increase. The characteristic size of the surface such as a heated-wire diameter does not become important unless the size is of the same order of magnitude as a bubble.

Burnout

As mentioned previously the peak heat flux in a constant-heat-input system is most important data. In saturated pool boiling if the maximum heat flux is exceeded the surface temperature will increase to a higher temperature. In many cases, depending on the material, the surface will not melt or

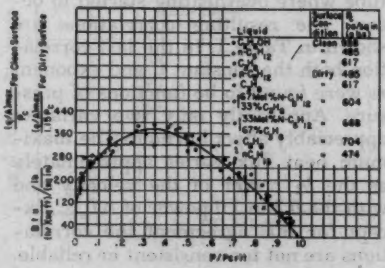

Figure 4. Correlation of data for condition of peak heat flux or burnout (ref. 5).

fail but will continue to operate at this high temperature. The prediction of this heat flux is believed to be quite reliable. Fig. 4 shows a correlation of data for these conditions. In addition to the data shown on the slide, several other investigators have obtained data for water which agree very well with the organic fluids used in the investigation shown in Fig. 4. The data were correlated as a function of the maximum heat flux divided by the critical pressure versus the ratio of the system pressure to the critical pressure. It should be noted that an additional constant of 1.15 was required to correlate data obtained for surfaces which were dirty. The maximum possible heat flux appears to occur around ⅓ of the critical pressure which in the case of water is about 1000 psi with a heat flux of $1\frac{1}{4} \times 10^6$ Btu/ft² hr. This is about three times greater than the maximum heat flux at atmospheric pressure.

For surface boiling with forced circulation the attainable heat fluxes are much higher than with pool boiling. A great deal of the research effort has been directed toward obtaining an understanding of burnout in this region. In most all cases the experimental data were obtained in a long heated tube. The tube generally burned out or started to overheat at the outlet end. The data reported were for the local calculated conditions at the exit of the tube where overheating started to occur. The resulting correlations are shown in Table 1. In the last correlation both the constant C and exponent m were found to be functions of pressure. Apparently only two variables appreciably affect burnout. The maximum heat flux varies approximately as the ½ power of the velocity and with the 0.2 to 1.0 power of ΔT_{sub}. Except for this agreement the correlations are not too consistent or reliable. Due to the simultaneous occurrence of an increase in pressure drop at the outlet section of the heated tube, together with the critical conditions of flow, fluid temperature, and heat flux, that have been called burnout, a satisfactory correlation is difficult to obtain. If the increase in pressure drop is sufficiently large compared to the over-all system pressure drop the flow in the tube tends to decrease. Since the heat input is obtained by electric-resistance heating it remains practically constant and the temperature of the fluid at the outlet end of the heated tube increases, resulting in conditions more critical than before. The pressure drop continues to increase and the flow continues to decrease until the heated tube is void of liquid and it overheats and burns out.

This autocatalytic effect has a greater tendency to occur in experimental systems which use a centrifugal pump and in which a large part of the total available pressure drop occurs along the heated tube. In many cases the flow instrumentation does not have a sufficiently fast response to detect a sudden decrease in flow at burnout. The flow before the autocatalytic event occurs is usually the recorded flow.

In systems in which a special effort is made to insure positive flow, the data become more predictable and reproducible. Higher heat fluxes are then obtained for the same flow rate and temperature at the inlet of the heated tube.

Many of the applications of nucleate boiling are in systems in which pressure drop remains constant, such as in heated parallel-flow channels. Without knowledge of the pressure drop the data obtained in a constant-flow system are not generally applicable. For this reason and because of the seriousness of a burnout prediction, the data and correlations shown in Table 2 should be used with caution. The correlations are most reliable at the higher subcoolings because of the smaller increase in pressure drop at burnout.

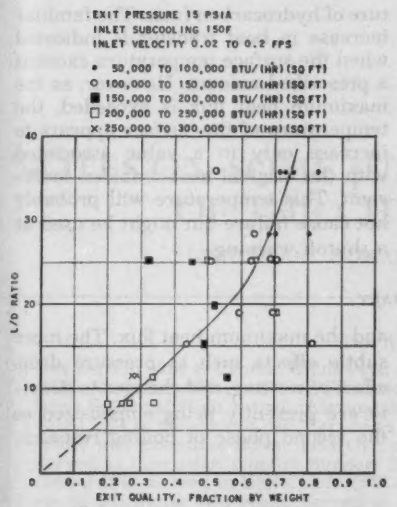
EXIT PRESSURE 15 PSIA
INLET SUBCOOLING 150F
INLET VELOCITY 0.02 TO 0.2 FPS
• 50,000 TO 100,000 BTU/(HR)(SQ FT)
○ 100,000 TO 150,000 BTU/(HR)(SQ FT)
■ 150,000 TO 200,000 BTU/(HR)(SQ FT)
□ 200,000 TO 250,000 BTU/(HR)(SQ FT)
× 250,000 TO 300,000 BTU/(HR)(SQ FT)
L/D RATIO
EXIT QUALITY, FRACTION BY WEIGHT

Figure 5. Effect of length-to-diameter ratio for a vertically heated passage (ref. 3).

Burnout for Net Boiling

A considerable number of experimental data indicated that heat fluxes as high as 3,000,000 Btu/hr ft^2 were obtained with calculated exit-steam qualities of 30 per cent (i.e., 30 per cent of the water by weight was vaporized at the heat-transfer surface). It was only with a great deal of difficulty that these data were obtained because of the high pressure drops that were developed. In a practical system it is normally not possible to attain these high fluxes. However, at reasonable fluxes and pressure drops, fluids that wet the heat-transfer surface can be vaporized to 80 per cent by weight without any large change in heat-transfer rates, if the surface transferring the heat is vertical and the heated passage has an L/D greater than 50. In the case of horizontal tubes or surfaces, flow separation might occur at very low qualities and the upper portion of the surface would overheat. Horizontal heat-transfer surfaces tend to overheat at the point where steam is first formed, since this is the point of lowest velocity and therefore the greatest possibility of steam separation.

Fig. 5 indicates the effect of length-to-diameter ratio for a vertically heated passage. As the length to diameter of the passage is decreased the exit quality at which overheating occurs decreases. In very short tubes the central core of liquid in the tube passes the heat-transfer surface before it can be mixed in order to come in contact with the surface and be vaporized. Therefore a considerable fraction of the fluid cannot be vaporized and the tube overheats at relatively low qualities.

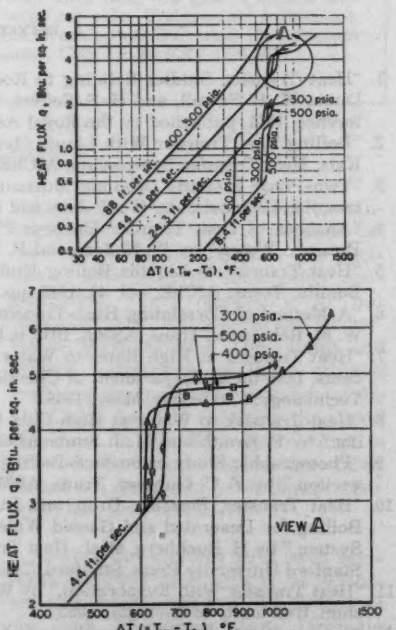

Figure 6. Heat-transfer behavior of a mixture of hydrocarbon fuels (ref. 1).

Boiling and Burnout With Two Components

Another item of significance in the utilization of boiling heat transfer is the boiling of a mixture of components, which are either miscible or immiscible. It is possible that burnout might be prevented by the addition of another fluid which has a slightly higher saturation temperature. Fig. 6 shows the heat-transfer behavior of a mixture of hydrocarbon fuels. The familiar increase in heat transfer is indicated when the surface temperature exceeds a prescribed amount. However, as the maximum heat flux is exceeded, the temperature of the surface appears to increase only to a value associated with the original heat-transfer coefficient. This temperature will probably not cause failure but might be used as a shutoff warning.

SUMMARY

The status of boiling research can be summed up as having passed through a first stage, in which a great deal of emphasis was placed on determining the effect of the properties of the fluid, and surfaces on boiling heat transfer, and the maximum heat flux. The more subtle effects such as pressure drop, effect of wetting, and changes in density are presently being emphasized as the second phase of boiling research.

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NOTES ON SOME JUNKS AND SAMPANS OF THE CHINA COAST

LIEUTENANT HOWARD BUCKNELL, USN

THE AUTHOR

was born in 1924 at Canton, China—son of Howard Bucknell Jr., then serving as a U.S. Consular officer in China. Education: château de Changins, Nyon, Switzerland, Episcopal High School, Alexandria, Virginia, U.S. Naval Academy, graduated 1944 in the class of 1945. Served as executive officer USS *LSM* 335, gunnery officer and executive officer LSM(R), commanded USS *LSM (R)* 514 in 1946. Served as instructor, Gunfire Support School, Coronado, California; Submarine School 1948. Served in USS *CUSN* (SSG 348) until 1952, was guided missile officer in *CUSN* for two years. Served as technical aide, Underwater Armament, Armament Branch, Office of Naval Research, Washington, D.C. until 1954. Present assignment: Executive Officer and Navigator, USS *POMFRET* (SS 391).

INTRODUCTION

There is probably no western navy more familiar with the Chinese Junk than ours. In past decades American sailormen have watched them, photographed them, sailed in them, boarded them, sunk them, cursed them, admired them, and, from time to time, inadvertently collided with them.

Every sailor who has served in the East can and will describe the junk at the drop of a hat. The discrepancies between these descriptions, however, are amazing. And yet, each individual account is very probably factual. Certainly there never was a generic family of seagoing vessels with a greater number of "in type" variations.

In attempting to determine what is a "typical" junk one faces quite a problem. There is no one junk. Furthermore, the literature on the subject is somewhat limited. A good many volumes have been published describing junks of one type or another but most of these descriptions are incidental to a story or some other consideration. Very generally in our literature the "red sails in the sunset" theme predominates. The quaint and artistic appearance of these oriental craft and the inevitable nostalgia of the old China hand in recalling the "good old days on the Whangpoo" tend to prevent the reporting of the more humdrum details of junk design construction, and function.

Among the authors who have seriously devoted their efforts to technical and comprehensive discussions of the junk, Worcester, Maze, Donnelly and Audemard certainly rank in the forefront. Dr. E. A. Peterson, Mr. Alfred Nilson, and Mr. John A. Bennett are three Americans who also

speak with authority on junks since they have both owned and sailed them. Mr. Nilson, in fact, lives with his family in New Rochelle, New York on board his junk "AMOY," named appropriately enough for her port of origin. The late Robert Ripley was another American who owned and sailed a Chinese junk, the MON LEI currently in the possession of the yachtsman, Mr. J. A. Bennett of Englewood, New Jersey.

To the American sailor the words "junk" and "sampan" have become accepted terms describing practically all of the myriad craft plying the waters of the East.

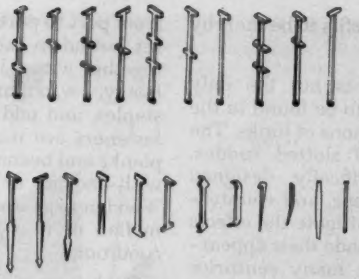
Worcester, who can be taken as an authoritative source without question, has remarked on the "—ominous silence—of—the great dictionaries and encyclopedias" on the moot question of when does a sampan become a junk or vice versa. In his books, he tends to use an overall length of thirty feet as the dividing line; anything smaller than this constituting a sampan, anything larger; a junk. An Upper Yangtze distinction has been advanced to the effect that a craft so narrow as to no longer permit a water-buffalo to stand athwartships is a sampan and not a junk. Dr. H. J. Wiens of Yale University has stated that the word "junk" is a Malay term denoting sailing craft whereas "sampan" is Chinese for "three planks." Thirty feet overall length, however is no doubt a perfectly satisfactory criterion. In general, with the exception of some Japanese fishing vessels, the Sampan is the small-boat of the Orient.

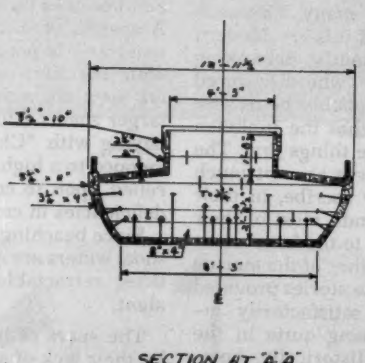
The trading vessels, fishermen, and armed coastal patrol vessels native to Indo China, China, and Korea can be called junks with equal appropriateness. The junks of China proper, however, are, in general distinguished by a sturdier, more workmanlike, construction. A higher degree of watertight integrity is achieved by the Chinese junk because of the comprehensive system of watertight bulkheads used in the hull division of many major types. For the most part, these bulkheads take the place of ribs or frames as we use them. The degree of compartmentation is prompted by commercial as well as marine considerations since, in many cases, space is sold by the Chinese Shipowner by compartments to merchants desiring to ship goods from one port to another. A prerequisite of this rented space is that it be susceptible to complete sealing and be well protected against the ravages of the sea or the thieving of passengers and crew members. It is perhaps incidental that the end result compares favorably with the most modern of Western conceptions of internal integrity.

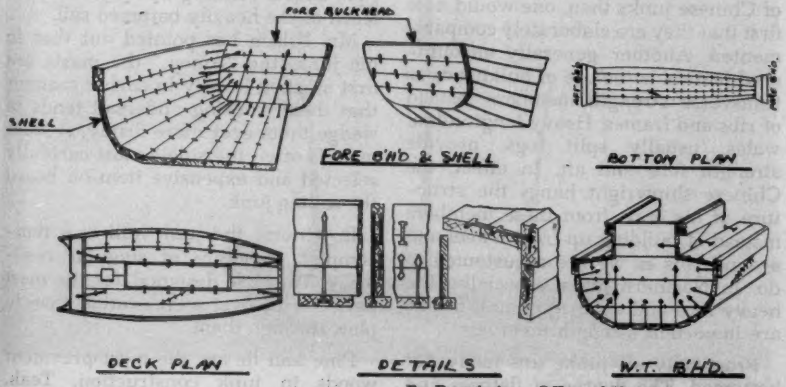
In categorizing their junks, the Chinese themselves, have employed first the method of describing the craft by the area in which it was built and then by the function which it serves. Thus we have a "Kiangsu Trader" or an "Amoy Fishing Boat." Sir Frederick Maze, former Inspector General of Chinese Customs, has pointed out that the Chinese have probably shown more originality than any other people in connection with shipbuilding. They have been particularly ingenious in designing vessels to suit special requirements and different conditions. Naturally, this has resulted in a considerable number of different type vessels.

THE CONSTRUCTION OF JUNKS

As has been noted, elaborate compartmentation is one of the distinctive features of seagoing Chinese junk construction. Marco Polo and Benjamin Franklin both remarked in their times on the extent of this internal hull di-







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Details of Junk Construction

vision and on the benefits to be thereby derived.

Internal integrity is not the only "advanced practice" to be found in the most ancient descriptions of junks. The counterbalanced and slotted rudder, the truly scientifically designed "yuloh" or sculling oar, and counter-flooding pockets to mitigate the effects of roll and pitch all made their appearance in junk design many centuries ago. The Chinese mariner's early use of the compass is common knowledge and certainly the Chinese junk was tacking to windward with sails sheeted fore and aft before many European sailors had developed this art. Modern historians are constantly debunking the older versions of "who discovered what" so it would probably be unwise to say categorically that the junkmen of China did all these things *first*. The junk sailors themselves are not much help here since they ascribe, in their own stories and legends, most of their major advancements to the benevolent action of one or the other of the marine gods or goddesses. The stories provided in this regard are satisfactorily involved and hair-raising quite in the seagoing tradition. Historically, however, they tend to be disconcerting.

In describing the usual construction of Chinese junks then, one would note first that they are elaborately compartmented. Another generally encountered feature is the use of bulkheads as transverse strength members instead of ribs and frames. Heavy longitudinal wales, usually split logs, provide strength fore and aft. In effect, the Chinese shipwright hangs the structure of his craft from these members instead of building up from a keel and around ribs as we are accustomed to do. In Northern junks especially, the heavy fore and aft cargo trunk beams are important strength members.

Practically all junks are fairly flat bottomed. The degree of flatness and the sheer of the hull in general varies from port to port. Planks are generally set butted to each other and fastened together with a liberal number of soft, heavy, wrought-iron spikes, nails, staples, and odd shaped pieces. These fasteners are inset or recessed in the planks and beams and are covered over with mortar or caulking compound. Wooden pegs are also reportedly used in lieu of iron fasteners under some conditions.

Pitch is very seldom used for caulking. A compound of lime and wood oil (tung oil) is generally favored. This compound acquires strength rapidly and becomes hard without brittleness. A species of oakum is laid along the seam and is pounded in and smeared with the lime compound. Discarded fish nets are sometimes used to caulk larger seams. The art of caulking and paying with "Chunam" has been developed to a high degree and is heavily relied upon to correct rather striking deficiencies in carpentry.

Since beaching and the navigation of shoal waters are almost universal practices, retractable rudders are prevalent.

The spars of junks are conspicuous by their lack of standing rigging. They are well stepped and the strain of their canvas is evenly distributed by multiple sheets running directly from the leech of the heavily battened sail.

Mr. Nilson has pointed out that in his junk, the "Amoy," the masts are first stepped loosely in such a manner that their working undersail tends to wedge them ever more firmly. A stout mast is often the single most carefully selected and expensive item on board the sailing junk.

In general the junk hull is a non-complex structure of singular resiliency. They are designed, for the most part, to ride over waves rather than to plow through them.

Pine and fir are the most prevalent woods in junk construction. Teak, mahogany, camphor, Siamese hard-

Official U. S. Navy Photograph

Official U. S. Navy Photograph

Mr. Nilson's Junk *Amoy*

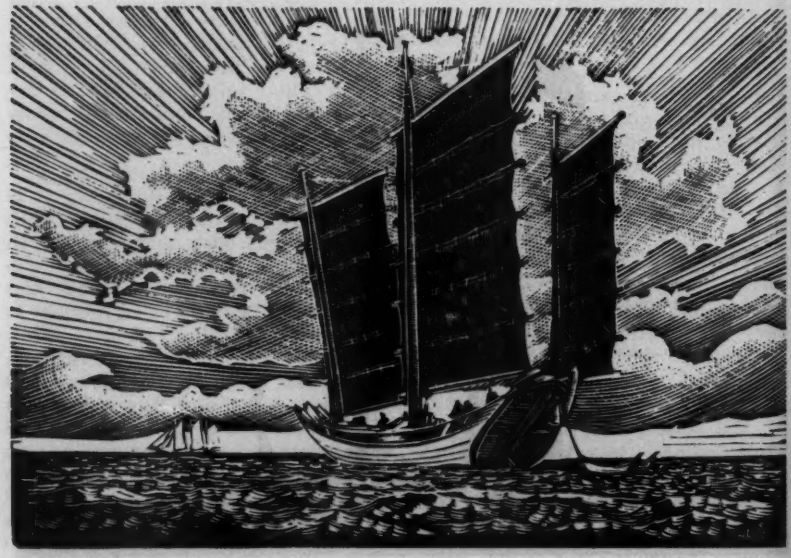
wood, laurel, cypress, and yacal woods are also common. Oak is used in the construction of some upriver Yangtze junks but is very seldom encountered on the coast. A very frequent combination is to have the hull constructed of fir, the transverse bulkheads of camphor, and sometimes the deck of teak. Camphor wood is sometimes used for hulls but even when not, a camphor paste may be encountered smeared on the underwater body. The aromatic properties of the camphor wood are reported to discourage the inroads of the Toredo Worm. It is conjectured that the odor and taste of camphor nauseates the worm and drives him to chewing moodily on seaweed instead of wood.

HULL TYPES

According to hull type there are two basic families of Chinese Coastal junks: those of the South and those of the North.

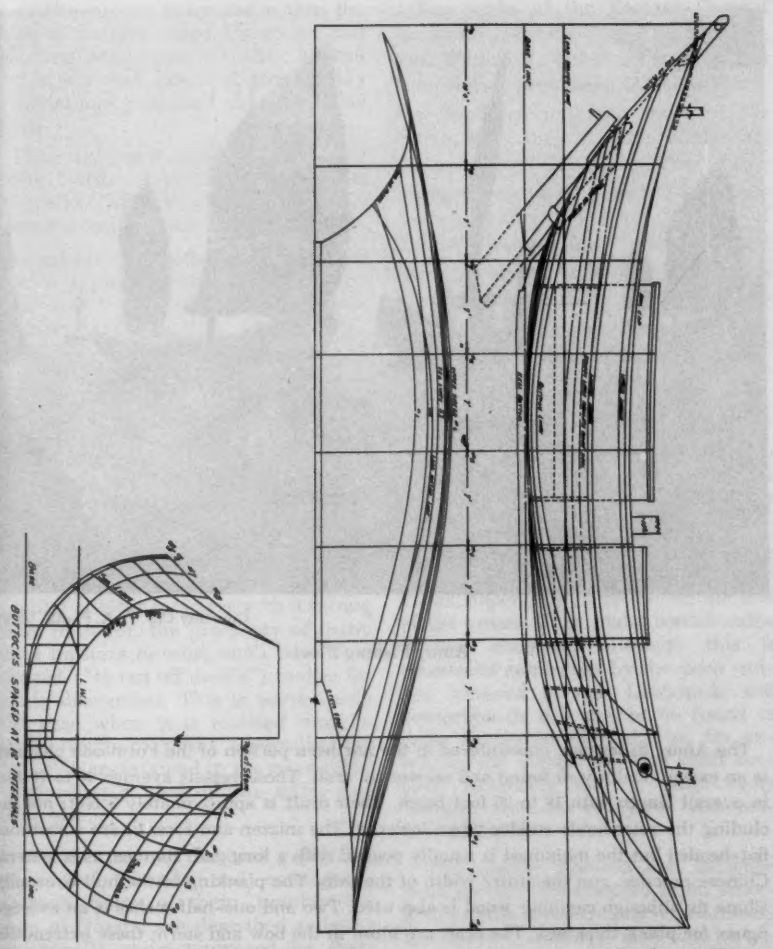
The basic difference between these two is that the Southern junks appear to show more of a western influence in their design than those of more northerly origin. Their hulls tend to be more rounded and they are built with a definite keel and with quite a pronounced counter. The underwater bodies are finer lined than those of the northern junks and they are generally more pleasing in their appearance—or as Donnelly puts it, "sweeter to the mariner's eye."

The Northern junks, on the other hand, are somewhat more box like in shape. The general principle of construction is the same but the appearance of smoothness and the finish of the Southern junk is usually absent in those of the North. The hulls of North-



Courtesy A. Nilson

Amoy Junk



Courtesy A. Nilson

Lines of Junk *Amoy*

ern junks are usually oiled instead of being painted. The general construction is characterized by great strength and stoutness with the deck usually curving to provide a "turret top." These vessels are peculiarly characterized by high bluff bows, low free board amidships, and a false stern built on by means of extending the sides of the hull on a rising line abaft the transom, where they are terminated by a shorter false transom. The deck surface of this extension serves as a prolongation of the deck of the after (and only) deck house and provides a platform for the rudder hoisting wind-

Courtesy Cdr. D. A. Plank, USNR

Amoy Fishing Fleet

The Amoy fisherman, encountered in the northern portion of the Formosan channel, is an exceptionally well found and seaworthy craft. These vessels average 40 to 70 feet in overall length with 18 to 25 foot beam. Their draft is approximately 3 feet; not including the retractable rudder when lowered. The mizzen and foresail are sometimes flat-headed but the mainmast is usually peaked with a long gaff. Battens, as is general Chinese practice, run the entire width of the sails. The planking of the hull is usually China fir although camphor wood is also used. Two and one-half inches is an average figure for plank thickness. The craft are blunt in the bow and stern; these extremities being formed by transverse planks laid butt-jointed against the fore and aft planking. The bottom is flat and formed by transverse planks although a small keel is generally added for protection. The hull is usually painted white with the upper works dark. A distinguishing feature is the accentuated forward rake of the foremast. The mizzen, when carried, is usually raked aft and is located on the starboard quarter.

Mr. Nilson's junk *Amoy* was built in 1922 for Captain George Waard. Captain Waard, his Chinese wife, and a coolie crew of three men crossed the Pacific in 87 days; running under sail from Shanghai to Vancouver. Mr. Nilson joined the crew in 1923 and subequently acquired ownership of the craft in which he and his family now live.

lass. The rudder is housed within the sides of the false stern. Cargo and sail handling windlasses are often located within the deck house. A stern galley is sometimes projected abaft the false stern.

Donnelly estimated that the bluff lined Northern junks approach the theoretical limit of wetted surface in comparison to displacement.

Common to both Southern and Northern junks are the heavy rubbing strakes or wales running the length of the sides outboard.

The junks of the Eastern Coastal ports and provinces (e.g. Ningpo, Chusan, Wenchow, Fukien, Foochow and Hangchow) provides a transition from the Southern junks to those of the North. With the exception of the fast disappearing LORCHA of Portuguese lineage, they lack evidence of western influence although some fineness of line is apparent. East China junks are probably the most striking to western eyes because of their colorful decorations.

JUNKS AND THEIR CREWS

On the whole, Chinese junks are extremely handy and responsive to the direction of their native crews whose familarity with their craft is a product of many generations at sea.

For the American Officer of the Deck dealing at close quarters with a fishing fleet, however, the proclivity of many junk masters to cross one's bow close aboard ("to cut off devils") makes for acute discomfort. This is particularly the case when it is realized that, in large Northern junks especially, the "conn" is maintained in the after cabin —affording a view of the sails—and little else.

The members of the junk guilds are particularly handy and courageous seamen. Some of them, notably the men of Ningpo are described as being universally short tempered by their shore-side countrymen. The game of mah-jong is reported to have been invented by Ningpo sailors to alleviate the effects of seasickness; although it has been suggested that another reason would be that Ningpo crews supposedly never put to sea with their wives and consequently suffer the pangs of boredom familiar to the sailors of our fleets. This practice may also, of course, have some bearing on their evil tempers.

At any rate the junk sailors with few modern tools at their disposal do an extremely fine job in sailing their ships.

Turning circles of junks are quite small, say on the order of 75 to 100 yards, depending of course on the size of the vessel. They make considerable leeway undersail although this is countered somewhat by the deep rudder lowered at sea. Leeboards and centerboards are also to be found in some categories of junks, as, for example, the Hangchow Bay craft employ leeboards and a good many Yangtze craft are equipped with centerboards.

The heavily sparred and battened sails are quickly lowered in an emergency. Sails of matting have practically disappeared although they will be encountered when canvas is in short supply.

The practice of installing engines in junks was given impetus during the Sino-Japanese War of 1937. This has continued on its inevitable way and more and more junks are to be seen with auxiliary engines. This will undoubtedly exert a marked influence on the standardization and merging of hull designs and methods of operation.

Courtesy Mr. J. A. Bennett

Mon Lei, built generally speaking along the lines of a Foochow Fisherman, is understood to have been originally constructed for the private pleasure of a Chinese Warlord in about 1939 by a Hong Kong Company. The late Robert Ripley purchased the vessel in about 1946 and upon his death it was acquired by its present owner, Mr. John A. Bennett for use as a private yacht.

Although of singular interest because of its history and its beauty of construction, *Mon Lei* does not strictly represent any one of the generic family of junks plying the coastal waters of China. The warm wheel house, the large diesel engine, and the cocktail bar below decks are innovations somewhat beyond the normal aspirations of the Chinese fisherman.

Under sail, junks can be expected to average two or three knots made good although speeds of seven knots or so are not uncommon.

Since most of the engines used in junks are converted truck types of doubtful vintage, the powered speed of a motorized junk would probably be about 5 knots. Higher speeds with decent engines are, of course, to be encountered.

As an incidental note, it should be remarked that the oculii or round eyes in the bows of some Chinese junks are commonly set staring downward for fishing boats to "aid in the location of schools." Traders, on the other hand, gaze straight ahead to ensure a safe voyage. Actually the oculus is not believed to be a native Chinese device. This is borne out by the fact that it is not universally used. It is seldom encountered on the Yangtze or in Cantonese waters, but rather appears most frequently around Ningpo.

JUNKS AND THEIR USES

Functionalism is the keynote of junk design. The Chinese shipwright is traditional in his approach but his reverence for tradition is solidly premised on common sense and on a very vivid acceptance of every day values. Many oddities of design make absolutely no sense at all until it is realized that their introduction was the result of economic pressures. For instance, to minimize the payment of local duty or tax some river junks are radically pinched at the waist where they were "measured."

There is, very probably, a junk or a

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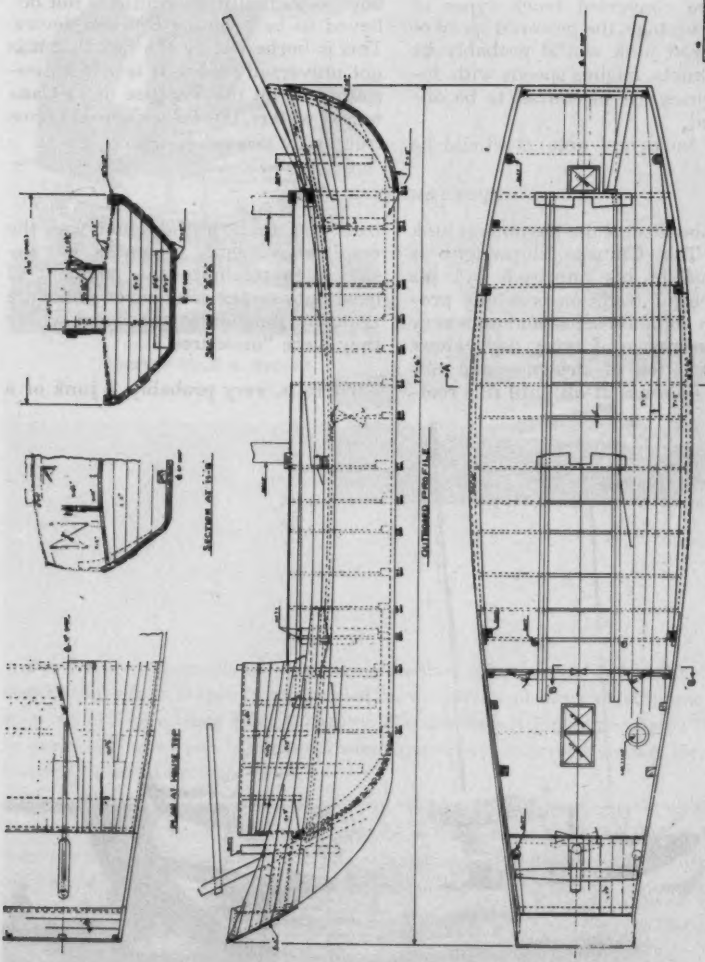
Two-masted Medium Northern Junk Beached—Chefoo Trader Type



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Plan of Medium Northern Junk—Chefoo Trader Type

Courtesy Dr. Peterson

Hummel Hummel, a small Ningpo junk—Over-all length, 36 ft.; beam, 9 ft.; draft, 2½ ft.

Ningpo junks are usually somewhat larger than the *Hummel Hummel*, averaging perhaps 50 to 70 feet in overall length with beams of 10 to 15 feet. Also they are usually three masted with the mizzen off center and raked slightly aft. The accentuated forward rake of the foremast is characteristic. Worcester has pointed out that a distinctive feature of Ningpo craft lies in the construction of the rudder; the rudder post and the first plank beading being carved from one piece. Sculls or "yulohs" are commonly carried. The full length battens are typically Chinese but the peak of the mainsail is somewhat higher than in Southern rigs. Ningpo craft are sturdily constructed with the usual multiple compartmentation. The triangular stem post is a Ningpo characteristic. Hull planking is generally of pine; bulkheads of harder wood. Small holes in the bottom at the bow permit free flooding—possibly in order to lessen the pounding sustained by the bluff hull running into a head sea.

sampan designed and built specifically to serve every function imaginable. There are junks for different methods of fishing, there are lumber junks and rice junks, salt junks, and coffin junks. There are sampans especially constructed for hauling ordure, for scavenging, for crabbing, for catching snails, for carrying singsong girls, and so forth.

Coastal junks are generally designed either for fishing or for cargo carrying. This obviously omits refinements of functionalism since there are coastal junks designed to carry particular types of cargo (as for instance the Foochow Pole Junks) and junks may often be encountered that perform coastal patrol or guard duties. These latter vessels will be armed and probably will be motorized. Together with junks devoted to piracy, however, these junks are basically either a fishing or a trading type and can be so classified.

JUNKS AND SAMPANS OF THE INLAND WATERWAYS

This paper is primarily concerned with the craft native to the coast of China. Upon entering any of the major ports or estuaries, however, it becomes evident that the river junks and sampans down river with their back country cargoes offer certain variations in design and appearance.

Generally speaking these river craft are built along the same lines as the coastal junks of the same region but they are somewhat narrower in the beam and tend to have taller masts. This is particularly noticeable in some Yangtze craft where the sails must be high enough to catch winds shielded from the river by high banks. River junks also have very shallow drafts and are built with little or no freeboard. Bows seldom flare upwards but are generally low. River junks are seldom painted but instead are usually oiled. Leeboards are employed quite frequently. Also compartmentation is apparently of lesser concern along the rivers than in the case of seagoing craft.

Poling gangways are common to river junks since this method of propulsion (as well as "tracking" by manpower) is often employed upriver in lieu of sailing or sculling.

The influence of function upon design is particularly apparent in the case of the upriver Yangtze junks of SZECHWAN. These craft are built with offset crooked bows or sterns to aid in the navigation of rapids.

A craft familiar to many American sailors is the Hong Kong Harbor Sampan. This small boat is usually found only in Hong Kong and reflects a good deal of western influence. The construction, with sharp stem, carvel-laid planking, western keel, and rounded stern is reminiscent of our sailing longboats. This similarity, however, is not enhanced by the gaff rigged Southern Chinese style sail. Pine is used extensively in the construction of these boats although camphor wood and lichee are employed for the frames and the stem. Yacal wood is found in the keel and teak, sometimes, for deck planking. The hull is almost invariably oiled rather than painted.

In sharp contrast to the Hong Kong Sampan, the Shanghai Harbor Sampan is exclusively Chinese in design. It usually has a red painted bow and is ducklike in shape. It is seldom sailed but most generally is propelled by "yuloh" or sculling oar.

CONCLUSION

This paper has only touched on a few of the major categories of junks and sampans of China. Worcester in his volumes has listed over one hundred separate and distinct categories in the middle and lower reaches of the Yangtze alone.

There is undoubtedly a junk type or variation for every imaginable purpose. Confronted with an outlandish and bizarre description—completely at variance with any junk design in one's own experience— it would probably be the wisest course to accept the description without demur—since, very likely it would be quite accurate and true.

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JET ENGINE THERMOCOUPLE AVERAGING SYSTEMS

ACKNOWLEDGEMENT

The author of this article is H. H. Chamberlain of the Meter and Instrument Division, General Electric Company. The article appeared in the December 1954 edition of *Aero Digest*.

The measurement of exhaust gas temperature in aircraft gas turbines is extremely important, since it gives an indication of both engine performance and engine life. At the present state of the art, thermocouples are used almost universally as primary detectors of exhaust gas temperature. Since thermocouples are sensitive to temperature only at one particular point, and since the exhaust gas temperature varies both radially and circumferentially inside the tail pipe or tail cone, it is usually desirable to use a number of thermocouples located at various points around the circumference of the tail pipe or tail cone. The average output of these thermocouples then provides a measure of the gas temperature.

An average temperature reading is usually obtained by connecting the thermocouples in parallel. Although series connections could theoretically be used, in practice this is not done for two rather important reasons:

First of all, in the series arrangement, if one couple open-circuits all indication is lost. This, of course, does not happen in the parallel connections.

Secondly, since thermocouple output is proportional to the difference in temperature between hot junction and cold junction, in order to get a true indication with the series connection it would be necessary to bring all of the cold junctions back to the instrument to obtain a reference junction. This, of course, would make for a bulky installation in cases where more than two or three thermocouples were required.

With parallel connections, there are three methods of obtaining an average reading in general use today, all of which are electrically and thermoelectrically equivalent if designed properly.

AVERAGING METHODS

The first method to be discussed and the one which might be referred to as the basic method, is that in which all thermocouples are of equal resistance and are brought to a common junction point as shown in Fig. 1.

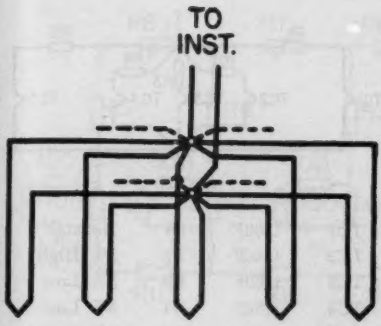


Figure 1. Basic averaging method is that with all thermocouples of equal resistance brought to a common junction point.

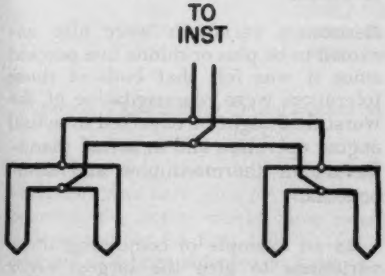


Figure 2. Variation of common junction type paralleling system can be used to average four thermocouples.

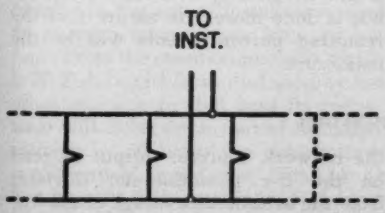


Figure 3. Ladder-type averaging system uses any number of equal resistance thermocouples all meeting in heavy conductors.

A lead is then brought from this common junction to the instrument terminals. Although this system can be somewhat cumbersome mechanically, since the distance from the various thermocouples to the common junction may vary, in value.

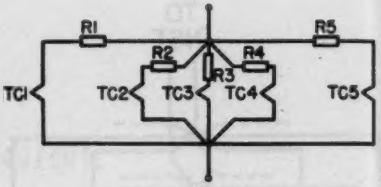
First, it is impossible to maintain exactly equal resistance in all of the thermocouples.

Secondly, as the thermocouples pass around the outside of the tail pipe to connect to the common junction, they pass through regions of varying temperatures. Since the combination of chromel and alumel wire has a temperature co-efficient of approximately 0.1% per degree F, an additional resistance error is introduced which is proportional to the difference in the average temperatures seen by the total length of the various couples.

The second method, (Fig. 2), which is a special case of the basic common-junction type paralleling system, is frequently employed when the output of four thermocouples is to be averaged. This system uses two pairs of thermocouples, all thermocouples having equal resistance. The two pairs are joined together at a common junction by means of two leads, each of equal resistance. The two leads are generally referred to as the harness, while the four thermocouples and their associated leads are known as the couples. This system, of course, is based on the same theory as the basic common junction method in that, under ideal conditions, the resistance from each thermocouple junction back to the common junction is equal.

The third type of averaging scheme, sometimes known as the ladder-type, is shown in Fig. 3. This system uses any number of equal resistance thermocouples all brought into a pair of heavy conductors of thermocouple material, the lead usually being brought out near the middle of this buss. From Fig.

3 it is clear that if the buss bars are made sufficiently heavy, the resistance values in the busses will approach zero, and the scheme then reverts to the common junction or basic type of averaging. For this system to be successful therefore, the resistance of the busses must be low compared to the resistance of the thermocouples. In practice, if the individual thermocouple resistances are 2.5 times as large as the total resistance of the buss bars, errors will be reduced to a point well within the guaranteed accuracy of standard thermocouple wire. For a spread of 100 F individual thermocouple resistances need be only 0.6 times the total resistance of the buss bars.



TC1	1200F	R1	Normal
TC2	1140F	R2	5% High
TC3	1260F	R3	5% Low
TC4	1260F	R4	5% Low
TC5	1140F	R5	5% High

Figure 4. A dc network setup simplifies work of determining inherent errors in the three systems.

COMPARISON OF ERRORS

A study of inherent errors in the three systems was made in order to be able to compare their performance. To simplify the work of determining these errors, a d-c network was set up to simulate the thermocouple circuit. This network is shown schematically in Fig. 4.

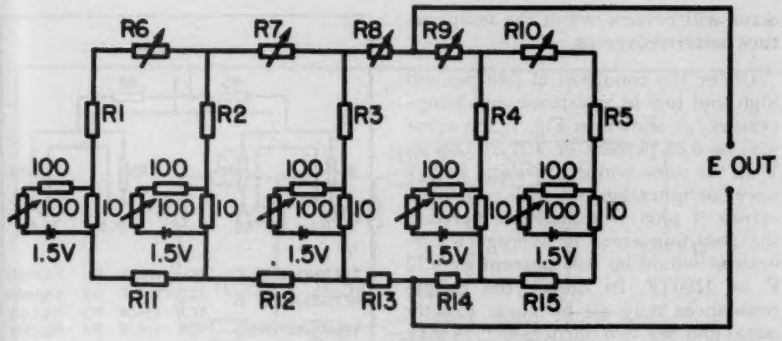
In the study of inherent errors, every attempt was made to pick the most unfavorable conditions of temperature patterns and resistance errors possible, so that the results given in terms of percent error would be the maximum.

In all cases temperature variations were set at plus or minus five percent, or a spread between couples of 10 percent. On the basis of 1200 F. average temperature, this would be 120 F. Resistance variations were also assumed to be plus or minus five percent since it was felt that both of these tolerances were representative of the worst that might be expected in actual engine operation and in actual manufacture of thermocouples and components.

As an example of combining these variations to give the largest error possible, it will be noted that when a thermocouple output is assumed to be high, the resistance of that particular thermocouple is assumed low, thus emphasizing the error. This, of course, is not necessarily a normal condition but is done merely to assure that the resulting percent errors will be the maximum.

ERROR DETERMINATION

For a typical error determination on the basic common junction type thermocouple paralleling system, a set-up as given in Fig. 5 using five thermocouples will be assumed. The temperature and resistance values will be as shown. Under these conditions, the network analyzer output as read on the d-c potentiometer deviates from the arithmetic average of the five voltages by 0.3 percent or 2.4 F at 1200 F. Since the error is proportional to a constant times the percent resistance error, if the couples had been selected



DC Analyzer Schematic
Set up for open ladder type harness

Thermocouple resistances		Note:
R1,2,3,4,5	20,000Ω Nominal	Parts may be rearranged to simulate other averaging methods, resistance values scaled up by 10^5
Harness resistances		
R6,7,10	4,460Ω Nominal	
R8,9	2,230Ω Nominal	
R11,12,15	1,860Ω Nominal	
R13,14	930Ω Nominal	

Figure 5. Typical error determination on basic common junction type thermocouple.

in such a way that their resistance variation was only plus or minus one percent, the error would have been 0.04 percent or 0.5 F at 1200 F. If the couples had been selected to have exactly equal resistance at room temperature, the error, again at room temperature would have been zero percent. Let us assume for the moment however that the conditions first described exist, and that one of these thermocouples in the actual installation, sees an average temperature from its hot junction to the common junction which is 50 F different from that seen by the other couples. In that case its resistance will differ from that of the other couples by 50 times the temperature coefficient of resistance (50x0.1) or five percent. It is in this type of error that the theoretical perfection of this basic averaging scheme falls down badly, since a 50 degree difference in average temperature for each one of the thermocouples over its entire length is not at all unlikely, but rather is quite probable.

For the equal resistance system, inspection and calculation show that the largest error occurs under the conditions shown in Fig. 6. The sign of the

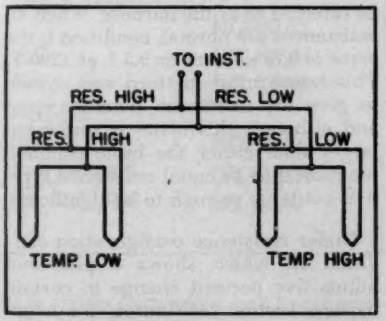


Figure 6. Conditions present in highest error calculation.

error will reverse when the temperature pattern reverses.

Under the condition of five percent high and low in resistance and temperature, as shown in Fig. 7, the error will be 0.25 percent or 4 F at 1200 F. With the same temperature and resistance configuration but with resistance errors of plus or minus one percent, the resulting error in average temperature would be 0.06 percent or 0.72 F. at 1200 F. In theory the couple resistances may all be made exactly equal and the two harness halves may be made exactly equal. In practice however, even if this is done, the same restrictions apply to this type of harness as apply to the basic common junction type: If the two harness halves, for example, pass through regions where the average temperatures are 50 degrees different from one another, then the resistance of the two harness halves will become unequal by five percent. Thus, it can be seen that in this type of averaging scheme as well as in the basic common junction type, it is somewhat falacious to refer to them as equal resistance systems, except under ideal conditions.

For the ladder-type system, calculations will be made on a five thermocouple arrangement with the temperature pattern shown in Fig. 8. Hereafter, the parallel buss bars will be referred to as the harness. When all resistances are normal, condition I, the error is 0.79 percent or 9.5 f. at 1200 F. This temperature pattern was chosen to give the maximum possible error and although this error is somewhat larger than either the basic common junction type or equal resistance type, it is not large enough to be significant.

Under resistance configuration condition II, which shows a plus and minus five percent change in certain harness section resistances, the averaging error is 0.8 percent or 10.2 F. at 1200 F. This relatively small increase

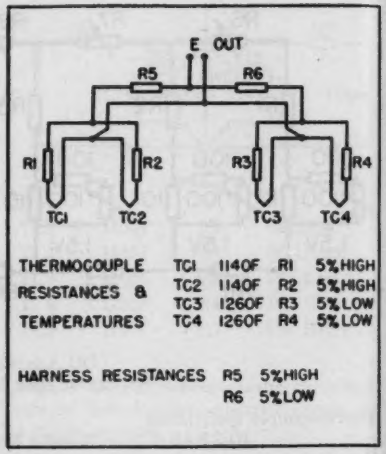
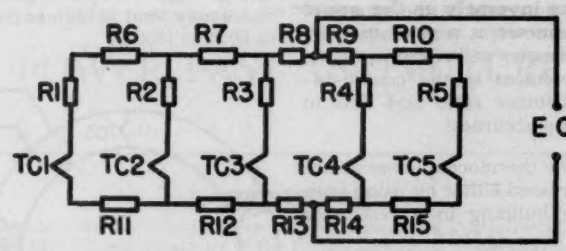


Figure 7. Error in these conditions will be 0.25 percent.

in percent error as resistance errors are introduced is, of course, due to the fact that the harness resistance is kept low. From this it follows that if the harness is made heavy enough to reduce its resistance to practically zero compared to the thermocouples, then any change in ambient temperature through which it passes has negligible effect on the accuracy of the average. This is natural, since the system has then been reduced to the basic common junction type, the busses now representing the terminals of the common junction system.

There still exists, of course, the same possibility of error due to varying couple resistance as existed with the common junction scheme. Resistance configuration III under Fig. 8 shows a temperature and resistance pattern similar to condition II except that now the couples have been allowed to vary plus or minus five percent while maintaining the harness sections at a more reasonable value of plus or minus one percent. Under these conditions the averaging error is 0.92 percent or 11 F. at 1200 F.



TC1 = 1200F TC2 = 1260F TC3 = 1140F TC4 = 1140F TC5 = 1260F

RESISTANCE CONFIGURATION

CONDITION I — ALL RESISTANCES NORMAL

CONDITION II

THERMOCOUPLE RESISTANCES		
	R1,R2,R3,R4,R5	NORMAL
HARNESS RESISTANCES		
	R6, R11	NORMAL
	R7, R10, R12, R15	5% HIGH
	R8,R9,R13,R14	5% LOW

CONDITION III

THERMOCOUPLE RESISTANCES		
	R1	NORMAL
	R2, R5	5% HIGH
	R3, R4	5% LOW
HARNESS RESISTANCES		
	R6, R11	NORMAL
	R7, R10, R12, R15	5% HIGH
	R8, R9, R13, R14	5% LOW

Figure 8. Temperature pattern for ladder type system calculations with five thermocouple arrangement.

Even these small errors may be further reduced in three ways.

First, the harness wire diameter may be increased. Since the harness resistance varies inversely as the square of the wire diameter, a very modest increase in diameter will result in a sizeable improvement in the couple-to-harness resistance ratio and thus in the averaging accuracy.

Second, the thermocouple resistance may be increased either by using finer wire or by building in a resistance winding.

Third, although perhaps this may not be quite as convenient mechanically because of engine configuration and possible interferences, the ladder may be closed as shown in Fig. 9.

In addition, errors present in the measurement system as a whole will tend to reduce the significance of the ladder type harness error. These errors which include thermocouple wire calibration tolerance, lead resistance changes due to ambient temperature change and cockpit indicator tolerances may total as high as five percent, or 60 F. at 1200 F.

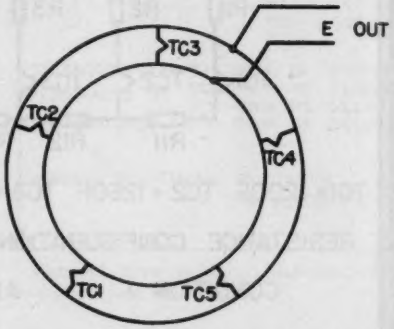


Figure 9. Schematic showing ladder closed.

CONCLUSIONS

Two general conclusions may be drawn on the basis of the foregoing discussion:

First, that there is little choice electrically or thermo-electrically between the various type of paralleling schemes for averaging the output of thermocouples in exhaust gas temperature measurement systems and

Second, that a number of advantages including lighter weight, greater design flexibility, and a cleaner mechanical installation may be obtained by the use of a properly designed ladder-type system without introducing significant averaging errors.

POWER: PAST AND FUTURE

ACKNOWLEDGEMENT

This article is the inaugural address as president of the Institution of Electrical Engineers, of J. Eccles, a member of the British Electricity Authority. It was published in the 15 October 1954 issue of *The Engineer*.

Some geologists compute the age of the earth to be about 3000 million years. Nine-tenths of that period passed without any event of significance to power engineers until about 300 million years ago, in circumstances which we can only conjecture, there seems to have occurred upon this planet a condition, or series of conditions, conducive to luscious vegetable growth over large tracts of its swampy surface. Vegetation grew, decayed, was reborn, and decayed, repeating its life cycle for perhaps tens of millions of years, until there was built up stratum upon stratum of hydro-carbonaceous matter.

Times changed, the climate altered, there were violent internal explosions with consequent disturbance of the earth's crust, dry land became the seabed, the valleys were exalted, the mountains were brought low, there were long periods of snow and ice, and never again have there been repeated in nature conditions so conducive to an accumulation of her precious hydrocarbon store. To this event, or series of events, we owe the coal measures and the oil wells which to-day provide over 85 per cent of the world's fuel. This garnering of nature's harvest being over, there is nothing of significance to relate until beings resembling man made their appearance about a million years ago. We know little that is not somewhat speculative about the evolution of man, before the period of recorded history. It is thought, however, that a million years ago he knew how to initiate and control fire, and it would seem that his progress since then has been conditioned as much by the state of his technology as by any other single cause. For a very long time men remained gatherers as distinct from producers. They were content to take what nature provided and use it as best they could. Later they assumed a more active role and endeavored to improve upon nature by tilling and fertilizing the soil, using domesticated animals for work and food and fashioning tools of stone and metal to increase the range and usefulness of their endeavors. It was in this latter phase that the demand for fuel grew apace. Wood was required for warmth, for cooking and for smelting metal, and whole districts were deforested by burning for no other reason than to provide wood ash as a ferti-

lizer. Large areas in India, China and other countries were devastated in this way, and when in these areas crops failed through lack of further enrichment of the soil, the population was decimated by starvation, and so the culture died that had blossomed in the previous age of plenty.

The record of these early civilizations seem to show that an improvement in technology encouraged an increase in population which overshot the capacity of the reigning technology to feed and to clothe, with the result that, in the exercise of that strongest human instinct — self-preservation — man with his limited knowledge unwittingly cut off the branch on which he sat. Thus it was that lack of knowledge of what nature held in store, and lack of knowledge of how to use efficiently the known resources, caused cultures of high rank to wither and, in some cases, to vanish from the earth.

However, the pattern was not even and, in some areas, improving supply technology, aided by slave labor, was able to meet the increasing demand for long periods. By 10,000 B.C. men knew how to make bricks, by 6000 B.C. they began to tap the fossil fuels, beginning probably with the most accessible deposit, asphalt. Earthen-ware vessels were made as early as 5000 B.C. The Chaldeans were skilful metal workers by 4000 B.C. Limestone was calcined and enameled pottery made in Egypt and Babylon by 3000 B.C. Asphalt was used in the building of the Pyramids and for waterproofing the walls of Jericho. In Babylon, roads were built by setting stones in ashpalt, a practice revived by J. L. McAdam some 2500 years later.

About 1000 B.C. the Chinese were using natural gas for fuel and lighting, which they procured from wells 3000 ft. deep and transmitted in bamboo pipes. According to Herodotus, an oil well was working on the island of Zante in 400 B.C., the lighter fractions being separated by stretching a hide over a cauldron of boiling oil and wringing out the condensed liquid.

The earliest recorded use of coal is 1100 B.C. in China. At that time, Chinese technology was sufficiently advanced to enable them to produce saltpeter, arsenic, mercury, vegetable oils, paper, sugar, printing and gunpowder. The first use of coal outside China was probably in Greece, and there is evidence that coal was known and used in Britain before the Roman occupation.

These apparently isolated, but perhaps not unconnected, examples of technological progress coincided, in some cases, with quite advanced civilizations, but it may be significant that almost invariably an improvement in supply technology was accompanied by an increase in population and by an arrogance or indolence in the governing body, which formed the seed-bed of decay. In this respect, things came to a head round about 500 B.C. In 538 B.C., Belshazzar was slain on the night of the handwriting on the wall and the Babylonian empire came to an end. In China, industrial progress ceased with the full flowering of the Confucian philosophy, and in India the caste system withdrew all intellectuals from the industrial crafts. Greek industrial progress died with Alexander the Great.

These events and others ushered in a period of 2000 years of technological stagnation in which, while fuel was still used for heating, little further progress was made in establishing man's command over nature. This period includes the Greek and Roman civilizations, which made little attempt to revive fuel technology. Greek intellectuals scorned those who tried to turn technical theory to practical advantage, and, though the Romans invented the waterwheel and the concave mirror for concentrating solar heat, their source of energy was almost wholly that of slave labor and animals

right to the end. What was needed was the discovery and application of means to augment man's energy and improve his transport. The Phoenicians had used the force of wind in sailing ships since 1000 B.C.; Hero of Alexandria came near to converting heat into work; the Romans used water power and the Chinese had used the explosive force of gunpowder. But no one knew how to harness nature continuously on the scale necessary to suit the growing human need.

It would be wrong to suggest that nothing happened anywhere during the Dark Ages. At the end of the Roman occupation, Britain experienced a political setback, but with the gradual emergence of more settled times the demand for fuel outstripped the current rate of vegetable growth and the countryside was being steadily denuded of its forests. Long before this, coal had been discovered as an outcrop and its value as a fuel was known. It was not a popular fuel, and in the reign of Edward I a decree was made compelling "all but smiths to eschew the obnoxious material and return to the fuel they used of old."

Thus we arrive at the fifteenth, sixteenth and seventeenth centuries A.D., with science and technology slowly awakening and facing the prejudices that had become entrenched in men's minds, without opposition, during their long period of hibernation. It was in this setting at the very end of the seventeenth century that an Englishman, Thomas Savory, invented the first successful steam engine and showed how heat could be converted into work. By means of this engine, improved by Newcomen and Watt, there was tapped an enormous reservoir of energy stored in the coal measures for 300 million years. The amount of power that was there for the taking seemed unlimited and the scale of human achievement made possible by this new mechanical aid dazzled the imagination. It was natural that the first applications of steam engines should be for pumping and winding at coal mines, but, once this main source of power energy had been made secure, their use became general. In 1827, the first steamship crossed the Atlantic to the New World, and in 1829 the first steam-driven railway locomotive was in operation. In 1884, Charles Parsons invented the first practical steam turbine, which so raised the sights in size and efficiency that today single machines are being designed for an output of 200,000kW using only ¾ lb of coal per kilowatt-hour.

Contemporary with these events in the realm of steam, work was in progress on the design of machines, in which controlled explosions of oil or gas could be translated into continuous mechanical power. The result was the internal combustion engine, which, apart from many useful fixed applications, completely revolutionized the mode, range and speed of transport. The first motor-car using this engine took the road in 1885, and the first airplane left the ground in 1903.

Prior to the emergence of most of these applications, Michael Faraday had discovered and demonstrated how a new and more versatile form of power could be made available. As every member of this Institution is aware, it was at the Royal Institution, London, on August 29, 1831, that Faraday first demonstrated the basic principle of electro-magnetic induction now used in every electric power generator throughout the world.

The result of these epoch-making inventions and discoveries has been that man, after surviving for nearly a million years on the gifts of nature as they were currently produced, and being frustrated from further development by the inadequacy of his technology, has in some parts of the world during the past 250 years developed a method of living that trans-

cends everything hitherto achieved, but is largely dependent upon the use in enormous quantities of natural energy stored in a bygone age.

Earlier in this address, I suggested that the present use of energy was equivalent to the service of twenty slaves for each person on this island, and I posed questions on the chances of this state of affairs being maintained and what is likely to happen if the supply fails. I shall now attempt a qualitative answer to these questions in the light of current knowledge.

Coal, oil and natural gas are wasting sources of energy, and in due course will cease to exist. It has been estimated that, in this island already, we have raised 25,000 million tons of coal and that the readily accessible coal remaining is about twice that amount. On this basis and at a modest increase in consumption we shall exhaust the accessable coal in about 200 years. The total coal reserve is probably very much greater, but much of it would be extremely costly to win.

It is not easy to estimate the total coal reserves of the world, and although attempts to do so have been made, the results are subject to many qualifications—the thickness of the seam, the quality of the coal, its depth below the surface and many other things have to be evaluated before its economic worth can be assessed. Economic worth is a relative term which depends on the availability and cost of alternative fuels. Liquid fuel enjoys a somewhat special relationship to all others.

A recent American assessment of the world reserves of all fuels is shown in Table I. This estimate suggests that the world reserves of crude oil are only about 5 per cent of world coal reserves, while, with 1:1 breeder reactors, the potential energy of nuclear fuel is more than twenty times as great as that of the world reserves of coal, oil and natural gas put together.

TABLE I*

Fuel	World reserves	Source of data	Total energy B.Th.U.
Crude oil	610×10^9 barrels	Weeks and Moulten	$\times 10^{12}$ 3.5
Natural gasoline	11.5×10^9 barrels	American Petroleum Institute	0.07
Shale oil	620×10^9 barrels	Bureau of Mines	4
Natural gas	560×10^{12} ft^3	American Gas Association ..	0.6
Coal	3482×10^9 tons	Bureau of Mines	72.2
Total conventional fuel	—	—	80
Uranium	25×10^6 tons	Raw Materials Division of A.E.C.	1700 at 1.1 breeding
Thorium	1×10^6 tons	Raw Materials Division of A.E.C.	71
Total new fuel (say)	—	—	1800

* Reproduced from Cisler, W. L.: "Economic Evaluation of the Industrial Use of Atomic Energy" (American Power Conference, March, 1953).

The world annual consumption of coal is about 1600 million tons and the consumption of crude oil is about 640 million tons. Unfortunately, simple arithmetic is of little practical value in computing the probable life of respective fuels in particular countries. There are some undeveloped countries with considerable coal resources in which the present use is negligible. On the other hand, highly developed countries are consuming coal at a rate disproportionate to their reserves. Furthermore, not all the known reserves are recoverable, although, on the other hand, more may be discovered.

With regard to oil, it has been estimated that consumption in the United States will be doubled between 1950 and 1975, and if this rate of increase were general the life of world reserves would be very much reduced. In view of the widespread tendency to use oil more extensively in agriculture and

for sea, air and road transport, the supply of this fuel may easily become critical within the lifetime of the present rising generation.

This all-too-brief survey lends color to the thought that, of the fossil fuels, oil will be the first to go. The efforts to produce a substitute liquid fuel may include the synthesis of coal, which, in turn, would accelerate the rate of destruction of this fuel. Even so, the reserves of coal are sufficient to allow time for the orderly development of alternatives. The geographical disappearance of fossil fuels will depend on the rate of uplift in relation to the amount of local reserves, and the rate of development of alternative fuels will depend, in the first instance, on their cost in comparison with that of local or imported fossil fuel. Obviously, the country with large reserves of all kinds of fuel is most favorably situated to maintain and expand its mechanized civilization, and provided it uses these resources economically and makes commensurate advances in its political and cultural life, it is probably destined to remain a world force for a longer period than other less well-endowed peoples. The importance, therefore, of the economical use of native fuel stretches far beyond the desirability of maintaining one's standard of living, although it includes it.

What, then, are the alternatives to fossil fuels? The general answer is nuclear fuel. I think, however, it would be wrong to give the impression that, although nuclear energy is there for the taking, it is a simple matter to release it in quantities suited to our requirements. Hitherto heat has been obtained by amputating and regrafting the limbs of matter; in nuclear fission, it is proposed to tear out and divide its heart.

It is not possible to make an accurate forecast of what the future fuel situation will be. There are so many imponderables, the frontier of knowledge is being constantly expanded, Nature herself may take a hand as in the previous Ice Ages, and the reaction of humans to changing circumstances must be given due weight.

The increase in world population is an important factor. Ever since man's emergence from the Dark Ages, world population has been increasing. Curiously enough, this has been noticeable even in countries where technology showed no advance. Perhaps the general trend has been made possible through better means of communication whereby the effects of industrial technology and medical science are felt beyond the confines of the countries that initiate them. Whatever the reason, most countries have participated in the production of a world population which has enjoyed a fourfold increase during the last 300 years and is now growing by 20,000,000 a year—that is, by more than 2000 an hour.

The fate of previous civilizations has been sealed when population outstripped the ability of their technology to provide sustenance and shelter, and the fate of our own cannot be dissociated from this self-same influence.

In this welter of possibilities, it may be of value to look at two possible alternative situations—one on the assumption that nuclear fission or nuclear fusion will not prove to be a practical means of providing power, and the other that it will.

Without atomic energy, the main alternatives to coal, oil and natural gas are water power, tidal power and wind power, with solar energy and geothermic heat available in certain zones, and wood, peat and animal wastes, each making its own contribution.

WATER POWER

The conditions which make water power most readily available are adequate rainfall on a large elevated catchment area, a suitable reservoir in which to impound water at this high level, a relatively steep conduit to a low level where the power unit is situated, and adequate means for disposing of the spent water.

Hitherto the assessment of world inland water power resources has included only those which show prospect of economic development and are not required for other purposes such as navigation, irrigation or domestic use. In future, much more may be pressed into service, perhaps for dual purposes of which power will be one. However, the most recent estimates show that the world total of inland water power, 40 per cent of which is in Africa, could supply at least three-quarters of man's present energy requirements.

One of the largest and most spectacular sources of water power lies at the western end of the Mediterranean. This inland sea loses water through evaporation which is not wholly recovered from its river inflow, with the result that water is constantly flowing through the Straits of Gibraltar, and to a lesser extent through the Dardanelles. If, therefore, both straits were dammed, the level of the Mediterranean would gradually fall, and having established a suitable differential it could be maintained by admitting water from the Atlantic through suitable turbines. Rough calculation shows that, with a differential of 70 ft., the inflow could develop 12,000,000 kW, which is 75 per cent of the present demand for electricity in Great Britain. It would require a modern Hercules to undo the work of his illustrious namesake, and no doubt the political repercussions would be considerable. The project is mentioned here only to illustrate the kind of thing that may have to be done in a more civilized world of the future when coal has ceased to be.

TIDAL POWER

Tides are produced by the combined gravitational effect on the earth of the moon and the sun. Since the liquid portion of the earth's surface is free to move, large oceans respond to the differential attractive force at the nether and the further shore. Winds and currents also play a significant part. The result is that, at any given point on the coastline of a large ocean, the tidal lift normally varies cyclically twice in the course of a lunar day, twice in the lunar month and twice a year. The amplitude of tidal lift varies from place to place. Since tides follow the moon and man's efforts follow the sun, the tidal cycle is not co-ordinated to human needs and, in this sense, tides are an unsatisfactory source of energy.

The simplest device for using tidal energy is to trap water in an estuary, or reservoir, at the time of high tide, and after the tide has receded sufficiently allow the trapped water to escape through turbines in which most of the energy due to the differential head is converted into useful work. The daily work periods are cyclic, and their incidence in time of day also traverses twelve hours during each lunar month. There are devices, such as pumped storage and double-basin working, by means of which the energy available for external work can be controlled and better fitted to human requirements. There is also a difference of up to two hours in the time of high tide at different places around our coast. If a powerful electrical transmission system were available to connect to-

gether all such points, it would be possible to take advantage of these time differences to reduce the amount of pumped storage. So long as the harnessed total energy formed a small proportion of the total energy in the electricity system to which it was connected, it could be accepted as and when it was available without storage.

The largest single tidal scheme in this country is that known as the Severn barrage, and much thought has been devoted to the most effective way of harnessing the energy in this estuary. A number of comparable schemes are being investigated in other countries, but no tidal energy project has yet reached the construction stage.

ENERGY OF THE WIND

Force is required to move air from one place to another, the corresponding energy being proportional to the cube of the velocity. It is practicable to abstract some of this energy by slowing down the speed of air movement.

Because of the low density of the medium, the energy release per unit volume for speed changes likely to be achieved in any practicable windmill is quite small. Stated conversely, a windmill must be a bulky structure with large-diameter vanes for even the relatively small output of 100 kW contemplated in recent designs. Furthermore, the wind bloweth where [and when] it listeth. It would seem that, although there is a large amount of energy of movement in atmospheric air treated globally, practical considerations will limit the contribution to be made by this source to a small proportion of man's present-day energy requirements. However, even this contribution may be welcome when coal and oil have disappeared.

SOLAR ENERGY

The amount of solar energy reaching the land areas of the earth's surface is equivalent to 10,000 times man's present requirements, and this may be the source from which the final scientific civilization will obtain its energy. Unfortunately, owing to the moderate temperature, the low intensity and the daily and seasonal variations, there is little hope of producing mechanical power by present known methods in any but tropical and semi-tropical regions. Interesting developments are taking place in domestic space heating and in solar cooking. Some 6000 solar cookers are being sold in India per annum, each capable of cooking a vegetable meal in about twenty minutes. If this practice extends, hundreds of millions of people will be able to cook their daily meal all the year round without using animal waste for fuel. Soil fertility should improve correspondingly.

Neglecting, therefore, for the moment the possibilities of nuclear fission, the most reliable and economical alternative to coal and oil is water power if one looks at the world as a whole. However, the locations of possible water power projects are such that quite fantastic power transmission schemes would be required to transport the energy to present centers of population. Apart from the political implications of such energy transfers across national frontiers they present technical problems of a scale and type quite beyond anything that has been solved hitherto.

An alternative to transmitting the energy to the people is to transport the people to the energy source, and a considerable shift in the weights of population may well take place in the future if nuclear fission proves to be intractable as a source of industrial power. Great efforts would, no doubt,

be made to ease the situation by developing tidal, wind and solar power in localities where there was little water power.

The foregoing assessment of the situation which may arise in the absence of a successful outcome of the attempts to harness the fission or fusion process for industrial purposes suggests that, when coal and oil are exhausted, it should be possible to muster man's present-day energy requirements from all the known sources, but that energy transmission or population transportation would present enormous technical and social problems. It underlines the absolute necessity to master the fission or fusion technique if the present pattern of civilization is to endure.

NUCLEAR ENERGY

Let us now look briefly at the nuclear power possibilities.

Professor Einstein postulated that matter could be converted into energy. He calculated that the annihilation of 1 lb of matter would release energy equal to 11,340 million kWh of electricity. Were such complete conversion possible, 6 lb of matter would release energy equivalent to the whole of the electricity generated in Britain last year. No means has yet been found to achieve this result.

It has been possible, however, to release a tiny fraction of the mass energy of matter by persuading a heavy atom to divide into two lighter atoms whose combined mass is a little less than that of the heavy one. Similarly, it has been possible to release energy by persuading a number of light atoms to form a single atom whose weight is a little less than the sum of the weights of the lighter atoms which combine to make it.

Fig. 1 illustrates some of the possibilities. In it are shown the deviations from whole numbers of the atomic masses of a number of elements on a scale in which the mass of oxygen is taken as 16. Some of these deviations are positive and some negative. Theoretically there should be a release of energy when atoms with a more positive mass deviation divide or combine to produce atoms of less positive or of a negative mass deviation. The division of uranium into two lighter elements or the fusion of hydrogen into helium offers the possibility of energy release. The diagram suggests that there are other possibilities.

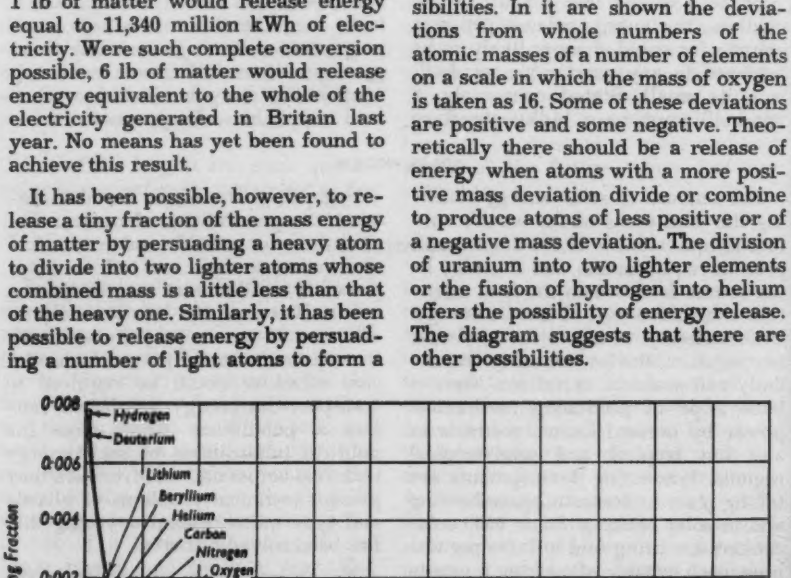


Figure 1.

Since hydrogen constitutes a substantial proportion of the earth's crust, the potential energy from the hydrogen-helium fusion process could be enormous. A practical difficulty is the sustained temperature at which this reaction takes place, and it would seem that, until something is discovered which will enable the reaction to proceed at a lower sustained temperature, the industrial application of this great energy source will remain unsolved. From published data on the fission of uranium, it would seem that the process can be controlled in such a way as to liberate heat at a temperature suitable for industrial power purposes, but that before efficient large-scale nuclear power stations are practicable, work has to be done on heat transfer methods and materials and on the treatment of the products other than heat which form part of the process. There can be little doubt that these problems will be solved if the need to do so is sufficiently great.

Of the uranium existing in nature, only about 0.7 per cent is fissile. However, a process has been devised through which the remaining 99.3 per cent can, by a double reaction, be converted into plutonium, which is fissile. Thus it is now theoretically possible to release in a controlled manner the energy of fission of all the uranium and perhaps the thorium content of the earth's crust. The practical and economic problem is to find the uranium and to separate and purify it.

From this point of view it is unfortunate that uranium is so widely dispersed among the other materials of the crust. For example, it has been stated that the uranium content of a ton of granite, if it could be isolated, would produce as much heat as a ton of coal. However, there is no known economical method of isolating the uranium content of granite, and this is equally true for trace contents in many other common substances. There remains, therefore, the problem of recovering pure uranium and thorium from their ores where they appear in forms and quantities that render the process economically practicable. It has been estimated that the availability and accessibility of uranium is such that (at present costs) an expenditure of £50 per pound of pure metal should be sufficient to mine and refine enough of this fuel to provide man's present energy requirements for 1500 years. Similarly, on the same basis, an expenditure on less productive ores of up to £100 per pound of pure metal should procure sufficient uranium to last another 8500 years. These very general figures should be taken only to indicate the satisfactory manner in which uranium can meet world energy requirements and, broadly, what effort would be required to render it available.

It is outside the scope of this address to forecast the international problems that may arise from the geographical distribution of fissile material in nature, but without wishing to minimize them it can be said that they will just have to be solved if all peoples are to enjoy the benefits of a mechanized civilization.

There are some who argue that, because it is now theoretically possible for nuclear fission to satisfy man's total demand for energy, the pursuit of all other sources should be abandoned. I do not share that view. There are problems to be solved before the energy of fission becomes a reality on a large scale. The chemical process of uranium separation and purification will itself consume a considerable amount of energy, and in any event the alternative sources will be fully competitive for many years to come.

As coal and oil approach exhaustion, a possible balance may be found by harnessing all the water power of the

world and, as far as possible, meeting local power requirements from this source. Where there is a local surplus of water power, the energy could be used to purify fissile material so as to provide power in lands where the alternatives are insufficient. Since fissile material, even in its natural state, is easily transportable; such packaged fuel might solve the power transmission problem.

Water power, tidal and wind power will, no doubt, be developed in many lands to minimize the need for imported fuel, and the world production of industrial alcohol will probably be greatly increased to provide much-needed liquid fuel. Indeed, one of the problems of the Atomic Age will be the provision of small mobile power units, and it may be that part of the answer will be found in the use of nuclear energy via a fuel cell. As far as can be seen at present, nuclear energy will be made available to the people as electricity. Electric rail and road transport will assume a new importance. Britain will become a smokeless zone.

In sum, therefore, man having evolved during a million years has, over the past 250 years, developed a mode of living which is unique in human history. This achievement has thus lasted for only 0.025 per cent of his sojourn here and already it has made great demand on the energy resources of our planet. Unless he is able and willing to match his technology to the unfolding needs of the situation, he has no presciptive right to a continuance of this latest civilization, and the history of civilizations discloses that discontinuity — decay and rebirth — is the normal method by which successive stages have been reached.

However, to-day man is equipped with a knowledge of natural laws (science) and an ability to harness these laws to his needs (engineering) that were absent in all previous civilizations, and there is good reason for thinking that the present mode of living can be greatly prolonged if he will but use this knowledge and ability aright. The test is one of competence in the political sense to learn how to live together in peace, and in the technical sense to unravel the unsolved relationships in nature and constrain them to serve his ends. The political aspect, though extremely important, and something for which all must share the responsibility, is outside our immediate scope this evening. But the progress of science and technology is the main object for which this Institution exists and, as events are shaping, is one of the two vital matters that will condition the future of the human race.

These twin challenges must be met if civilization is to endure, and members of this Institution are in the front line on one of the battlefields. It is an exciting situation. The need for more and better physicists, chemists and engineers was never more clamant, the results of achievement were never more worth while, and it is extremely important that in our homes and schools the need and the prospect should be fully explained to the rising generation on whose shoulders the responsibility for continuity lies.

We stand before the portals of an epoch. It is the privilege of scientists to unlock one of the doors through which humanity may pass to the enjoyment of a fuller and a freer life for the next 5000 years.

Let us all see to it that man is worthy of his achievements.

CONDENSED WORLD WAR II HISTORY OF NEW ZEALAND SHIPPING

COMMANDER ARTHUR C. BUSHEY, USN, RET.

THE AUTHOR

Commander Bushey is a registered architect and registered professional engineer in the State of Maryland. Since his retirement in May 1953, he has been engaged as a consulting engineer in Baltimore. During this period he has also been vitally concerned with research and development of laminated plastics, a project he fostered while stationed in Contract Design (Hull), Bureau of Ships from 1946 to 1952.

During his last year of active duty, he served as the Senior Assistant Supervisor of Shipbuilding and Naval Inspector of Ordnance and Assistant Industrial Manager, Baltimore. During World War II he was attached to the South Pacific Command, later serving as officer in charge of shipbuilding and ship repairs in New Zealand and commanding officer of the U.S. forces in Auckland.

The late King of England invested him as an Honorary Officer of the Military Division of the Most Excellent Order of the British Empire. He was also made an Honorary Commander in H.M. New Zealand Coast Guard and for his service in the South Pacific he was decorated with the Bronze Star Medal.

INTRODUCTION

It is readily recognized that waterborne commerce is a vital matter to the comparatively small island country of New Zealand, a country whose primary industry (in their parlance) is agriculture. As one of the British Commonwealth nations it is evident that her sea lanes are often of great length. Part I of this paper gives the merchant vessel losses in the first half of World War II to show at a glance the staggering blow dealt by the enemy to both imports and exports during the most critical period in the life of the Empire. Part I also relates some dramatic epics of the sea.

During the second half of World War II, ships flying the United States flag overcrowded the ports of Auckland, Wellington and Napier and quite often filled Lyttelton and Dunedin harbors.

Part II relates to an early contribution in the post war era made possible by United States wartime activities.

PART I—NEW ZEALAND MERCHANT SHIPS, WORLD WAR II

The extent of loss of supplies from other parts of the Empire, suffered by New Zealand may be gleaned from Table I. It itemizes the ship loss to New Zealand of those vessels regularly engaged in the New Zealand trade, which were not on New Zealand's articles.

An account is given of seven New Zealand ships. The first, the *Pamir*, is unique because it is a sailing vessel.

TABLE I

New Zealand Merchant Shipping Lost

No.	Ships Location	Dead	Survivors	Date	Causes
1	S.S. *Turakina* (off New Zealand in Tasman Sea)	35	23	Aug. 23-40	Raider
2	S.S. *Cumberland* (off northern coast of Ireland)	4		Aug. 23-40	Torpedo
3	S.S. *Remuera* (off north coast of Scotland)		All	Aug. 26-40	Aerial torpedo
4	S.S. *Hurunui* (off north coast of Ireland)	2		Oct. 14-40	Torpedo
5	S.S. *Cambridge* (in Bass Strait: Tasmania-Australia)	1		Nov. 7-40	Mine
6	S.S. *Rotorua* (off Scotland)	18		Nov. 11-40	Torpedo
7	S.S. *Rangitane* (off east coast of New Zealand)		500	Nov. 27-40	Shell fire by three raiders
8	S.S. *Middlesex* (in Bristol Channel)		All	Jan. 10-41	Mine
9	S.S. *Huntingdon* (out of Swansea)		All	Feb. 21-41	Torpedo
10	S.S. *Somerset* (400 miles west of Ireland)		All	May 11-41	Aerial bombs
11	S.S. *Piako* (120 miles off Capetown)	10		May 11-41	Torpedo
12	S.S. *Norfolk*	1		June 18-41	Torpedo
13	S.S. *Otaio* (North Atlantic)	13	58	Aug. 28-41	Submarine
14	S.S. *Nottingham* (North Atlantic)	61	None	Nov. 1-41	Aerial bombs
15	S.S. *Opawa* (North Atlantic)	57		Feb. 16-42	Torpedo
16	S.S. *Hertford* (off south coast of Australia)	Some		Mar. 29-42	Torpedo
17	S.S. *Westmoreland* (North Atlantic)	3		June 1-42	Torpedo
18	S.S. *Surrey* (Caribbean Sea)	12		June 10-42	Torpedo
19	S.S. *Dorset* (in Malta Passage)			Aug. 13-42	Submarine or plane
20	S.S. *Empire Avocet* (300 miles from Freetown)	2		Sept. 29-42	Torpedo
21	S.S. *Empire Whimpbrel*		All	Apr. 11-43	Torpedo or gunfire
22	S.S. *Samsip* (in Scheldt River)	7		Dec. 7-44	Mine
23	S.S. *Empire Manor*			Jan. 27-44	Collision in convoy
		—	—		
	N.Z. Shipping Co. & Federal Steam Savigation Co.	244			
	Employees loaned to other companies	18			

The second, the *Maunganui*, is recorded because of her outstanding performance in carrying the wounded. The remaining five, the New Zealand owned ships lost due to enemy action in World War II, are worthy of more than passing mention to those who go down to the sea in ships. It is appropriate to observe that in naming their ships, New Zealanders often use the place names given by the old Maori inhabitants, just as we draw upon those given by the American Indians.

Pamir

The *Pamir* is a four-masted barque of 2,796 gross tons. She was built in Hamburg in 1905. During World War I she was captured from the Germans and subsequently handed over to the Italians. Later she was reacquired by the Germans, who sold her to Captain Ericson, the Finnish owner of a fleet of twelve sailing ships which carried grain to all parts of the world. She made an outstanding record in the 1931 grain-cargo sailing ship race from Australia to the United Kingdom.

On July 29, 1941, the *Pamir* arrived in Wellington with a cargo of guana from the Seychelles Islands. Strained relations existed at the time with Finland, so upon suggestion by authorities of the United Kingdom, New Zealand detained the ship administratively until word was received that relations were broken. She was then taken over as a prize. There were fourteen Finns (including the master), one Swede, seven New Zealanders and one Englishman in the complement. The Union Steamship Company of New Zealand, Ltd. became the managing agent for the New Zealand Government. Alterations were made to the crews quarters and minor repairs effected. During the war period she made six round trip voyages from Wellington to San Francisco and two from Wellington to Vancouver, carrying valuable cargoes each way.

Maunganui

The *Maunganui*, a steel vessel of 7,527 gross tons, was built in 1911 at Govan, Scotland for service between New Zealand and Australia. Upon the opening of hostilities in World War I she was taken over by the New Zealand Government as a troop ship, serving during the entire conflict to transport New Zealand Forces to the European theater of operations. After the war she returned to the New Zealand-Australia run.

In January 1941, the *Maunganui* was commandeered by the New Zealand Government for the second time. She was given a quick and rather costly conversion to a hospital ship and left Wellington on 21 April 1941 on the first of her seventeen cruises, steaming a total of 400,000 miles and carrying 10,000 patients. Nine cruises were made from Wellington to Suez, four to Mediterranean ports, one to Glasgow from Italy, one to Leyte, one to Hong Kong and Manila and one to the United Kingdom. She returned to Wellington on 23 March 1946 and was immediately made ready as a transport to take the New Zealand contingent to the United Kingdom for the Empire Victory Celebration.

Holmwood

The *Holmwood*, a steel vessel of 546 tons, was the first New Zealand ship lost due to enemy action, in World War II. Built in 1911 at Goole, England, she was acquired in 1923 by the Westland Shipping Company for carrying coal and timber from New Zealand ports on the Tasman Sea. In August 1940, the *Holmwood* became the property of Holm and Company, Ltd. for the New Zealand-Chatham Islands trade. It was on her second voyage to the Chatham Islands for her new owners that she was sunk by a German raider on 24 November 1940. The crew and passengers of the *Holmwood*, a total of 29, were taken on board the raider and

were landed on Emirau, in the Bismarck group, after the members of the crew had signed agreements not to serve on defensively armed ships and the male passengers had also agreed not to bear arms nor undertake military action against Germany or her allies during hostilities. An Australian vessel rescued the 29 persons from the island of Emirau. They landed in Sydney, Australia on 6 January 1941. The Matson liner, *Mariposa*, carried them to New Zealand, arriving in Auckland on 13 January, 1941. No lives were lost in this incident.

Komata

The *Komata* was the second New Zealand ship lost due to enemy action. The *Komata* was a modern steel cargo vessel of 3900 gross tons and was built in Glasgow, Scotland in 1938 to the order of the Union Steam Ship Company of New Zealand, Ltd. On her usual Pacific run, on 8 December 1940, just two weeks after the sinking of the *Holmwood*, two Japanese ships were sighted off the island of Nauru. The larger vessel, about 8,000 tons, headed for the *Komata*, ordering her to stop and not to use her radio. The master of the *Komata* bravely ordered his radio operator to send a message for help. Before the message could be sent, the raider put three well directed shells into the *Komata*. The first went through the eyes of the ship, the second shattered the wireless masts and equipment, and the third hit the bridge. The third shell killed the first mate and critically injured the second mate. The crew were taken aboard the raider, where the second mate died from his wounds. There was a repetition of events as in the *Holmwood* sinking; the crew were landed on Emirau Island and released after concluding agreements not to serve on defensively armed ships during the hostilities. The survivors were picked up, taken to Sydney, Australia and from Sydney to New Zealand by the *Maunganui*, arriving in Wellington on 18 January, 1941.

Hauraki

The third New Zealand ship lost to the enemy, the *Hauraki*, a steel motorship of 7,113 gross tons with a 3500 b.h.p. propulsion plant, was built in Dumbarton to the order of the Union Steam Ship Company, of New Zealand, Ltd. She arrived in New Zealand on her maiden voyage in June, 1922. At that time the *Hauraki* was one of the largest motor-ships afloat. She was engaged in trade between New Zealand and Australia and the west coast of North America until 23 July, 1940. On that date, the *Hauraki* was taken over by the New Zealand Ministry of War Transport. In the Indian Ocean, enroute from Freemantle to Colombo, on 12 July, 1942, she was captured by two armed Japanese raiders. The raiders ordered her to proceed to Penang after putting a prize crew aboard. Before the enemy boarded the *Hauraki*, the New Zealanders were successful in dumping secret documents, mail and correspondence overboard. It was realized later that they had overlooked nine mail bags of secret Navy mail in a locker at the after end of number two hold. Mr. A. F. McIntyre, the second officer, pretended that he was ill and was thereby able to escape detection in reaching the locker during the early morning hours. He passed the mail to the chief engineer, Mr. W. C. Falconer, at the hatch. They hid the mail bags and between them dropped the bags overboard when afforded an opportunity. This act of devotion to their homeland was made in spite of the Japanese warning that anyone found near the hatches would be shot or beheaded. Mr. Falconer also disposed of all plans, instruction books and as many spare parts as he could. He also pumped oil overboard each night to form a trail which he hoped would be seen by a rescuing vessel. This was in vain, because at that time U.S. and

British naval vessels in the Pacific were hard put. When the *Hauraki* arrived at Singapore, the master, chief officer, chief engineer and senior radio officer were taken off and sent to Yokohoma by transport. The majority of the crew were also removed and put in Changi Prison Camp. The remaining engineers and a few other specialists were retained on board the *Hauraki* until she reached Japan in January 1943, when they were sent to Tokyo Prison Camp. Five men died while prisoners of war. The remainder were safely returned to New Zealand during September and October 1945.

Awatea

The *Awatea* was the fourth ship lost through enemy action. During her short life, she was probably the most outstanding vessel owned in the Southern Hemisphere. Built of steel, of 13,482 tons, at Barrow-in-Furness for the Union Steam Ship Company of New Zealand, Ltd., she had passenger accommodations for 528 passengers, representing the last word in appointments and convenience. Her modern propelling machinery provided an average speed of 23 knots. The *Awatea* arrived in New Zealand in September 1936 for the passenger run to Australia. In July 1940, she was taken over by the Ministry of War Transport and made several trips to Vancouver. On 27 October, 1941 she left Vancouver and proceeded to Honolulu, Manila, Hong Kong, Singapore (24 November 1941, 14 days before Japan entered the war), Colombo, Mombassa, Cape Town, Trinidad and arrived in Liverpool on 18 January, 1942. She left Liverpool on 15 February 1942 for Freetown, Durban and Bombay, returning to the Clyde on 29 May, 1942. She left the Clyde on 29 June, 1942 for Durban, Cape Town, Bermuda and Halifax. On 22 August she left Halifax and at 2230 her bow collided with a destroyer which attempted to pass through the line of convoy ahead of the fast *Awatea*. The *Awatea* was damaged and the destroyer had an explosion resulting from the collision. After repairs had been completed on the *Awatea*, she again left Halifax, on 29 September 1942, arriving in Glasgow on 7 October 1942. She left Glasgow for the last time on 24 October 1942 to participate in the Allied Landing in North Africa. Enemy bombers attacked her off Cape Carbon, North Africa on November 11, 1942. After gallant action by her crew in engaging the bombers, she was torpedoed by the enemy. Fortunately, no lives were lost.

Limerick

The fifth and last ship lost to the enemy was the *Limerick*. She was a steel refrigerated cargo vessel, of 8,724 gross tons, and built in 1925 at Glasgow for the Union Steam Ship Company of New Zealand, Ltd. She was engaged in service between New Zealand, Australia and the west coast of North America. The *Limerick* was taken over by the New Zealand Ministry of War Transport in October 1940. She rendered valuable service in many capacities. On 26 April, 1943 she was torpedoed and sunk by a Japanese submarine off the coast of Australia. 55 of her complement of 57 were rescued.

PART II—NEW ZEALAND ACQUIRED VESSELS—POST WORLD WAR II PERIOD

When Commander Southern Pacific announced his intention to visit Auckland in his flagship, the U.S.S. *Vincennes*, in January 1946, I informed the New Zealand Government of the estimated time of arrival. The Marine Department of the New Zealand Government immediately replied by telegram, "Is the *Vincennes* surplus?"

The humor of the query was greatly appreciated. It was a reminder of our mutual seeking for answers as to what

purchases should be made of U.S. surplus property then available in the Pacific.

Three surplusYTLs, truly beautiful, powerful and efficient 75-ft. steel tugs, built under the U.S. Shipbuilding Program in New Zealand, were sold to the New Zealand Government, who turned them over to UNRRA to partly fulfill one of her commitments. New Zealand was enabled completely to fulfill her obligation by using U.S. surplus material to complete eight 45-ft. tugs, originally intended for the British Eastern Supply Group (which were almost identical to those built under the U.S. Shipbuilding Program) and by building eight 55-ft. steel fishing vessels in Auckland, four at Mason Brothers and four at Seagar Brothers, and sending them to UNRRA.

The fourth surplus YTL was sent to Westport Harbor where it was sorely needed in that important coaling port on the west coast of the South Island. It is to be remembered that the *Holmwood*, the first New Zealand ship sunk by the enemy, had been on the Westport run. The fifth surplus YTL, ex-USS YTL-622, was retained in Auckland Harbor chiefly for towing vessels to Greenhithe.

Three surplus YFs from the U.S. Shipbuilding Program filled immediate demands for additional New Zealand coastal shipping and provided stopgaps during the much needed overhauls of vessels which made coastal runs during the war years. The *Aranui*, ex-YF-1046, and the *Rosalie*, ex-YF-1048, were chartered in May 1946 by the Northern Steamship Company, Ltd. to carry fertilizer on both coasts. The *Melva*, ex-YF-1047, was later assigned to coastal service. These diesel-propelled cargo vessels of 114 ft. 6 in. length, 24 ft. beam, moulded depth of 11 ft. and cargo capacity of 260 tons were ideal for their post war service. They did require, however, a waiver from the New Zealand Marine Department, because they did not meet Board of Trade requirements in that the steel beam spacing was 21 instead of 18 inches and the Oregon Pine planking was 3 instead of 3½ inches thick.

It was too early in 1946 to plan for the future of New Zealand shipping. Further it is almost axiomatic that vessels should be designed and built for the particular service intended. Changing world conditions did not permit simple replacement of ships lost or worn out during World War II.

MARINE DIESEL ENGINEERING PROGRESS IN 1954

ACKNOWLEDGEMENT

This staff article is reprinted from the January 1955 issue of *The British Motor Ship*.

The constant development of engines is one of the problems, challenges and, some say, the tragedies, of marine engineering, an engine no sooner being installed than a better design is on the drawing board. It is one of the apparent anomalies of the industry that an engine, which may have undergone only minor modification over many years, when introduced in its new form, appears concurrently with other engines incorporating the results of similar lines of development.

These instances of independent lines of development coinciding with the progress of other engineering concerns are not, in fact, coincidences: they are the natural outcome of either anticipating or having to comply with current demands of the shipping industry. The shipowner in the light of service experience, and the first to feel the impact of trends in economic conditions, is able, if he has suitable and capable engineering advisers, to suggest to an appreciable extent the line of engine progress.

Had there not been the demand for engines to operate on boiler oil, engineering concerns might not have sought to adapt their engines for that purpose. If shipowners were not generally seeking higher powers for their tankers and cargo liners, marine Diesel engineers would not have found the same ready acceptance for exhaust-gas turbocharged machinery. But for the recent reforms of tonnage regulations, the shipowner would have found little gain by the adoption of supercharged machinery or would have shown as little enthusiasm as has been witnessed until recently, in highly-pressure-charged four-stroke geared-Diesel installations.

It is to be regretted then, that shipping is often slow to follow in the wake of technical advances, and initiative and enterprise are confined to such a comparatively small number of superintendents, confidently backed by their companies. The development of an engine is to meet the needs of the shipowner, not the engine-builder: the shipowner, therefore, must familiarize himself to a greater extent with what has already been achieved and what is now available.

TURBOCHARGED MACHINERY

With the advent of turbocharged two-stroke Diesel machinery, the perhaps natural interest is in what maximum power can be developed by a single engine. It is fair to say that the exhaust-gas turbocharging of such engines was largely accomplished to meet the higher powers required in tankers of increased carrying capacity. However, with substantially fewer tankers being ordered, and with owners of dry cargo ships seeking to take advantage of the new tonnage regulations, supercharged two-stroke engines are being specified for medium and quite low-powered ships.

Thus, there have been ordered or completed two-stroke engines ranging from 12,500 b.h.p. down to 1,970 b.h.p. in pressure-charged form. The B. and W. engine was, of course, the first to enter service as an exhaust-gas turbocharged unit and its adoption has hitherto been the most extensive. Well nearly 150 such engines are now on order or in service, the continuous rating at present being limited to a value corresponding to an m.e.p. of about 7.1 kg. per sq. cm., or 101 p.s.i., compared with about 5.2 kg. per sq. cm., or 74 p.s.i., for the non-turbocharged unit. This represents an increase in the specific output of about 35% and, on a horse-power basis, a reduction in weight and space requirements of about 25% and 20% respectively. Owing to the higher mechanical efficiency—89.5%—the fuel consumption is about 3% lower.

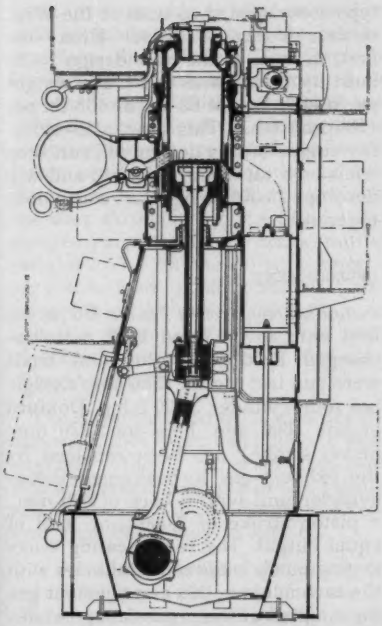
It is one of the peculiarities of present world economic conditions that Japan, the first country to build the new design of Sulzer engine described later, and which is likely to put into service the first supercharged M.A.N. two-stroke engine of a high power—about 12,000 b.h.p.—also built in 1954 a Burmeister and Wain turbocharged two-stroke engine of very high power. This is installed in the "Harunasan Maru," the first of three 10,000-ton cargo liners, and develops 11,250 b.h.p. or 12,690 i.h.p. at 115 r.p.m. A generally standard single-acting two-stroke unit, it has nine cylinders 740 mm. in diameter with a piston stroke of 1,600 mm. There are three B.B.C. exhaust-gas turbochargers and the total engine length is 52 ft.

We later inspected in London a sister ship, the *Hoeisan Maru* which had maintained in service an average speed of slightly more than 18 knots, fully loaded. The engine-room length of 68 ft. in this ship is obviously providing an excess of spaciousness and on the subsequent ship the length is being reduced by about 2 m., which gives about another 10,000 cu. ft. of cargo space. All these vessels are running on boiler oil.

In contrast to this 11,250 b.h.p. machinery, it should be noted that a passenger-car ferry scheduled for completion by Aalborg Vaerft, A/S., Denmark, early this year, is to be propelled by two turbocharged two-stroke B. and W. engines each developing only 1,970 b.h.p. at 300 r.p.m. They have seven cylinders with a bore of 350 mm. and a stroke of 620 mm.

NEW STORK TWO-STROKE ENGINE

We have described in detail in the past the new Stork single-acting two-stroke engine suitable for turbocharging and for operation on boiler oil, and since then a number of orders have been placed. The first ship to be propelled by this new engine entered service in May, this being the m.s. *Ouwerkerk*, a 10,250-ton cargo liner built by Netherlands Dock and S.B. Co., for the United Netherlands Navigation Co.



Section through cylinder of the new Sulzer engine.

The engine in this vessel is an eight-cylinder unit with a bore of 750 mm., a piston stroke of 1,500 mm., and, with the m.e.p. increased by turbocharging to 6.3 kg. per sq. cm. (89.5 p.s.i.) and the scavenging air pressure to 0.34 kg. per sq. cm., the output is 8,500 b.h.p. This represents the modest increase in output of 18% with a fuel consumption on test of about 150 gr. per b.h.p.-hr., or 0.33 lb. The ultimate aim for this engine is 9,000 b.h.p. with an m.e.p. of 94 p.s.i. (6.6 kg. per sq. cm.) or an increase of 25% over the unsupercharged unit.

Originally ordered as a normally-aspirated unit, the engine in the *Ouwerkirk* retains the engine-driven scavenging air pump at the forward end, although the pump is disconnected and on subsequent engines will be eliminated.

The B. and W. two-stroke turbocharged engine has dispensed also with the engine-driven scavenging air pumps but they have been retained at this stage on the Werkspoor and Doxford designs. It is likely, however, that the new design of Sulzer engine, which has been tested for turbocharging, will discard its engine-driven scavenge pumps.

This class of Sulzer engine is generally similar to that of the engines with a 580-mm. bore installed in a number of geared-Diesel-engined ships for the New Zealand Shipping Co. These engines, however, run at 225 r.p.m., whereas those which have made their first appearance in the course of 1954 are designed for direct-drive and run at 115 r.p.m.

The first was a 10-cylinder unit built by the Harima S.B. and E. Co., Japan, followed closely by an engine of similar size by the Havre works of the Forges et Ch. de la Mediterranée. This design complies in every respect with the details given by Mr. Kilchenmann of Sulzer Bros., in the paper read before the Institute of Marine Engineers in London. The engine may be of welded steel or cast iron construction but that which we examined at Havre when on the test bed was welded and had eight cylinders of 760-mm. bore and a stroke of 1,550 mm. At 122 r.p.m. it has a maximum rating of 9,100 b.h.p. but the service output is 8,300 b.h.p. at 118 r.p.m.

Of the crosshead-type, this engine is designed for operation on boiler oil, a diaphragm carrying a stuffing box preventing contamination of the crankcase oil by combustion deposits, while the fuel pumps are fitted close to the cylinder heads to ensure good injection of the heavy fuel. The fuel consumption is about 161 gram. (0.355

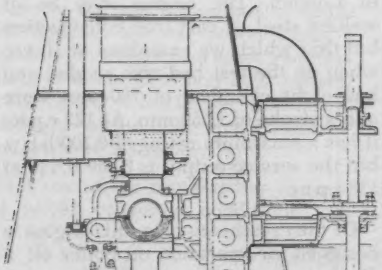
lb.) per b.h.p.-hr. and at 115 r.p.m.; the scavenging air pressure is 0.175 kg. per sq. cm.

This, the first European-built engine of the direct-drive type, was installed in the 7,200-ton cargo liner *Duquesne*, which entered service in May for Cie. Cyprien Fabre. More recently a 10-cylinder, 10,000 b.h.p. engine of this type completed shop tests at the Winterthur works of Sulzer Bros.—the first, in fact, of the new design to be built by them—and this has a weight per metric h.p. of 62 kg. or 138 lb. per (British) b.h.p. This year, a 12-cylinder engine of this design will run shop trials as a turbocharged unit, and will develop 15,000 b.h.p. in continuous operation.

DOXFORD ENGINE DEVELOPMENT

This has been the greatest year of Doxford engine development for a considerable period, new arrangements being introduced to isolate the cylinders from the crankcase to ensure greater reliability when operating on boiler oil; oil cooling arrangements for the lower pistons being made available; a new fuel injection system developed and, their first turbo-charged engine has now been installed in a ship.

The need for a pressure-charged Doxford engine has long been realized, the advent of higher powers for all classes of ship, and the demand of the shipping industry for shorter engine-rooms adding impetus to research in this direction. The M.T. *British Escort*, owned by the British Tanker Co., is the first ship to be fitted with a turbo-charged Doxford engine and trials were run last month. The ship's original four-cylinder 3,200 b.h.p. Doxford engine (600 mm. bore by 2,320 mm. piston stroke) has been replaced by the exhaust-gas turbocharged three-cylinder unit with a bore of 600 mm., a piston stroke of 2,000 mm., and of equal output. The reciprocating scavenging pump is operated in series with the turboblower, this arrangement being adopted at the present stage of developments for safety reasons.



Sectional arrangement of Doxford diaphragm engine, showing diaphragm, and telescopic piping for cooling the lower piston.

To suit the power requirements of the ship, the supercharge is limited to 30% but it has been stated that a 50% increase in power has been attained.

The British Tanker Co. are to be congratulated on their enterprise in installing this engine in one of their tankers, while to the Elder Dempster Lines goes the credit for placing the first order for a turbocharged Doxford engine for regular commercial duty. This, to be built by Scott's S.B. and E. Co., will be a six-cylinder unit with a bore of 670 mm., a combined piston stroke of 2,320 mm. and an output of 8,000 b.h.p. at 115 r.p.m. and is for a 10,000-ton 16-knot cargo liner.

The possibility of corrosion in the crankchamber when operating on boiler fuel is one which offers serious consequences and, like most other marine Diesel engine builders, Dox-

fords are now able to offer an engine with complete isolation of the crankcase from the cylinders. The Doxford Diaphragm Engine, as it is termed, is the standard unit with certain, but not extensive, modifications. Briefly these comprise the eliminaton of the lower piston skirt; the construction of the piston rod with a parallel shank which operates through a gland fitted with scraper rings; a length/crank radius ratio of 3.55:1 for the center connecting rod instead of the normal 4:1; the extension of the center guide plate to suit the shorter connecting rod and, of course, the provision of the diaphragm chamber.

The attractive feature of this development is that it can be applied to new engines without increased cost and that such diaphragm plates and glands can be fitted without difficulty to Doxford engines already in service.

It should also be noted that oil-cooling of the lower pistons is now available for these engines, the choice being given between lubricating oil-cooling with telescopic piping, or the use of the normal design of swinging links but with increased bore for either oil or water cooling.

Before leaving the subject of Doxford engines, it may be mentioned that the past year was for us memorable in that we had the opportunity to see for the first time a geared-Doxford installation. This was in the American-built passenger liner *Fairsea,* built in 1941 and the sole survivor of four similar ships taken over by the U.S. Navy; the propelling machinery comprises two Sun-Doxford engines rated at 4,500 s.h.p. at 180 r.p.m., with a cylinder bore of 21 in. and a combined stroke of 60 in. Both engines drive the single propeller shaft through Westinghouse electric slip couplings and single-reduction 2.14:1 gearing to give a propeller speed of 79 r.p.m. A notable feature is the provision of two electrically driven scavenging air blowers.

There is, we believe, ample scope for reflection in the fact that in the past five years, this vessel, manned by an Italian crew, has averaged at least 330 days per annum at sea, with a mean service speed of 16-17 knots.

ENGINE PERFORMANCE ON BOILER OIL

In keeping with current demand, Götaverken engines also have been adapted to operate reliably on boiler oil, considerable experience having been obtained since 1953 with three ships propelled by these engines and running continuously on fuel with a viscosity of up to 3,800 sec. Red. 1 at 100° F. A considerable number of engines are now on order with Götaverken and their licensees to operate on residual fuel so that now, every make of slow-speed direct-coupled unit is able, as was the original intention when the Diesel engine was first invented, to operate on fuels of cheap and varying grades.

There remains some doubt as to the advisability or need for auxiliary Diesel machinery to run on the cheaper fuel, although one or two shipping companies have already taken this step, but it is interesting to note that some makers of medium-speed Diesel engines are pursuing research in this direction. This may well be in view of the growing but cautious interest in geared-Diesel propulsions, but particularly promising results are being attained by Mirrlees, Bickerton and Day, Ltd., who are conducting a thorough investigation into the performance of one of their K-type engines. This is a turbocharged three-cylinder four-stroke unit running at 428 r.p.m. and developing 621 b.h.p. when coupled to a dynamometer.

In spite of some difficulty encoun-

tered in the burning of heavy fuels in the K-type engine, it is considered by those responsible for these investigations that the application of sound and available engineering remedies makes it both a practicable and attractive proposition. Some modification of an engine must be expected to give equivalent performance on heavy oils but with certain amendments, good service can be obtained on low-grade fuels to show a "handsome reduction in overall running costs."

Mirrlees are actively developing the highly supercharged four-stroke engine in Great Britain, but to the M.A.N. has gone the credit of engining the first ship to have highly supercharged four-stroke machinery, this vessel, the *Lichtenfels* being a cargo liner of 9,000-tons d.w.c., propelled by twin six-cylinder reversible 2,800 b.h.p. engines with a b.m.e.p. of 16 kg. per sq. cm., or 227 p.s.i. Both engines drive the single propeller through Vulcan reduction gear.

Of the crosshead type and designed to operate on boiler oil, the engines have a fuel consumption in the region of 140 gr. per b.h.p.-hr., or 0.31 lb. Each has a cylinder diameter of 450 mm. and a piston stroke of 660 mm., the supply of combustion air being by means of a M.A.N. multi-stage axial blower, but a radial blower is to be used for subsequent engines.

On the desirability of building larger engines of this class, M.A.N. contend that this would be uneconomic, since the modern large slow-running engine has been developed to the extent that its fuel consumption is no more than 150 gr. per b.h.p.-hr., and, moreover, by increasing the size of the highly supercharged four-stroke engine, certain thermal difficulties will be encountered.

TURBO-CHARGED LOOP-SCAVENGED ENGINE

What is believed to be the first engine ordered and built as a turbocharged loop-scavenged two-stroke marine engine entered service in September in the 3,240-ton *Frederick T. Everard*. Built by the Newbury Diesel Co., Ltd., this is a Sirron P-type six-cylinder engine with a bore of 407 mm., and a piston stroke of 648 mm.

The normal b.m.e.p. of 64 p.s.i. is increased by exhaust-gas turbocharging to a maximum of 91 p.s.i., at which the engine develops 1,700 b.h.p. A Napier exhaust-gas turbine is fitted and the exhaust-gas pressure before the turbine is 4.65 p.s.i., while the turbine discharge pressure is 3.6 p.s.i. The tandem double-acting scavenging air pump at the forward end of the turbine has been retained and, in emergency with the turbine blanked off, a speed of 7-8 knots could still be obtained. As a pressure-charged engine, the weight per b.h.p. is 105 lb. as compared with 135 lb. for the equivalent non-pressure-charged unit.

EXHAUST-GAS TURBOCHARGERS

The axial-type turbochargers for the highly supercharged M.A.N. engines operate with the inlet pressure to the turbine at 2.1 atm., the temperature being 500° C. and the back pressure 1 atm. The quantity of gas passing through the turbine is 4.4 kg. per sec., the speed being 9,700 r.p.m., in normal service, with a maximum of 11,000 r.p.m.

Of the axial-reaction type, the number of stages in the turbine is limited to three and the compressor, direct-

coupled to the turbine, has 14 stages. The pressure ratio is 2.5:1. At full load the efficiency of the supercharging unit is 68%.

The adjacent illustration is of the first Rateau turbocharger to be fitted to a B. and W. two-stroke engine—a seven-cylinder unit developing 8,750 b.h.p. at 115 r.p.m. There are, in fact, two of these blowers on the engine, now in service in the East Asiatic Co.'s M.S. *Sumbawa*, and, in all, 10 Eriksberg-B. and W. engines are to have this form of blower. One of the designs, a 10-cylinder 12,500 b.h.p. unit, will have three such blowers. A smaller type is being adopted for six more engines, including two of nine cylinders and developing 11,250 b.h.p. These also will have three turbo-compressors. Most of the turbocharged B. and W. two-stroke engines have Brown Boveri blowers, while the first Harland and Wolff opposed-piston engine of the class just completed is equipped with Napier turbo blowers.

NOHAB SUPERCHARGED ENGINES

Good progress also is reported by Nydquist and Holm A/B., Trollhattan, Sweden, in the exhaust-gas turbocharging of their Nohab two-stroke industrial and marine Diesel engines. Investigations were undertaken on a Polar marine-type three-cylinder engine (180 mm. bore x 300 mm. piston stroke) which developed 195 b.h.p. at the normal running speed of 700 r.p.m. These resulted in the introduction of the company's turbocharged E-class engines which for traction and industrial stationary duties has an output 40% higher than that of the non-supercharged unit while, for marine purposes, the power increase is limited to 30% to comply with existing classifications for the crankshaft.

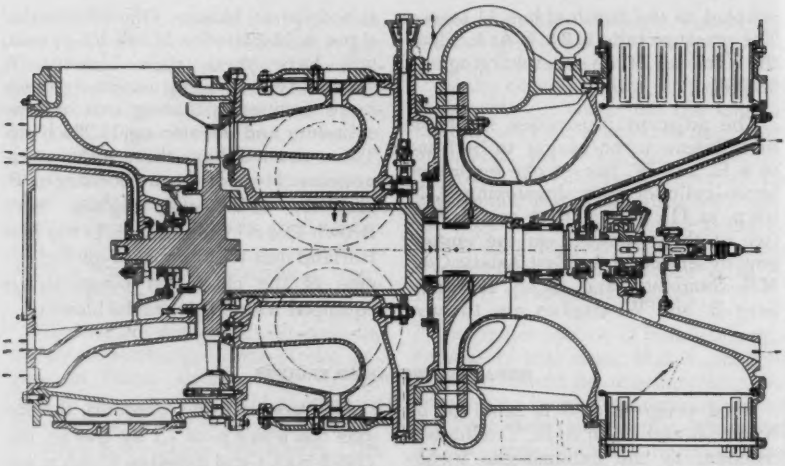
As a pressure-charged unit, the engine has a m.e.p. of 7.7 kg. per sq. cm. (109.5 p.s.i.) and develops 91 b.h.p. per cylinder at 700 r.p.m., the weight per b.h.p. being 11 kg. (at 40% supercharge) as compared with 14.9 kg. for the normally-aspirated unit.

Pressure-charging tests have been extended recently to the new Nohab six-cylinder N-type engine. This is a unit suitable for operation with an m.e.p. of 6 kg. per sq. cm. (85.3 p.s.i.) and a bore of 340 mm., with a stroke of 570 mm. It has outputs of 1,140 b.h.p. at 300 r.p.m., 950 b.h.p. at 250 r.p.m. and 835 b.h.p. at 220 r.p.m.

GAS TURBINE PROPULSION

The application of the gas turbine to marine engineering remains, in value, somewhat an enigma, the tendency to dismiss it as being of no consequence being halted by the rapid progress shown in its development and the attention being paid to it by most of the large marine engineering concerns.

Prospects that Great Britain would have the first all-British gas-turbo propelled merchant ship in service have been lessened by the recent announcement that the U.S. Maritime Commission is placing an order with the General Electric Co. of America for a 6,000-b.h.p. open-cycle gas turbine to replace the 2,400-b.h.p. reciprocating steam machinery in a Liberty ship. The turbine will be of the manufacturers' standard regenerative cycle of two-shaft design, essentially a repeat of 38 machines already supplied to drive centrifugal compressors in long-distance pipe-line pumping, coupled to a 5,000-kW. A.C. generator.



Longitudinal section through a Rateau turbocharger.

The turbine will be rated at 6,120 b.h.p. at 5,480 r.p.m., and double-reduction gearing will give the controllable-pitch propellor a speed of 100 r.p.m. It is intended that boiler oil complying to G.E.C. specification will be used after starting up on Diesel oil. It will, therefore, be of considerable interest to see whether the U.S. vessel can be brought into service before the 18,000-ton Shell tanker, scheduled for completion next year and to be fitted with two gas-turbine-driven alternators supplying current to two electric motors which will drive a single propeller shaft through a two-pinion single-reduction gearbox. Each of the turbines will develop 4,150 b.h.p., and the British Thomson-Houston Co. and Cammell Laird and Co. will make the components, the turbines being tested at the Birkenhead works of Cammel Laird under B.T.H. supervision. Of the open-cycle type, the gas turbines will have two-stage compression with intercooling, and will operate on boiler oil.

Japan, too, is actively pursuing gas turbine development, the Mitsubishi Nippon Heavy Industries, Ltd., having recently built an experimental 2,500-s.h.p. unit suitable for marine or industrial stationary application. Designed for a maximum gas inlet temperature of 700° C., or about 1,290° F., the unit has a speed of 8,000 r.p.m. at the driving turbine. It is estimated that a thermal efficiency of 31% will be attained.

The fact that free-piston gas generators and turbines for marine propulsion and auxiliary duties cannot be ignored in importance was emphasized recently when the 850-ton cargo vessel *Merignac* entered service with 1,200-s.h.p. machinery of this class. The two gas generators each have an engine cylinder bore of 340 mm., a compressor bore of 900 mm., and a maximum stroke of 550 mm., the full load stroke being 443 mm. At full-load output, the number of cycles per minute is 613 while the gas is delivered at a pressure of 3.0 kg. per sq. cm. (43 p.s.i.) and a temperature of 440° C. (825° F).

THE STRESSES IN A SIMPLY SUPPORTED REINFORCED ANNULAR PLATE UNIFORMLY LOADED

IRVING GRANET

THE AUTHOR

was born July 2, 1924. Attended Brooklyn Technical High School and received Bachelor of Mechanical Engineering Degree from Cooper Union in 1944. Served two years with Air Corps overseas as Flight Engineeer. Employed 1944-45 on Navy Torpedo project as project engineer on stress and vibration studies. Since 1947, employed as project engineer, Research Department, Foster Wheeler Corporation. In June 1948 received Master of Mechanical Engineering Degree from Polytechnic Institute of Brooklyn and in 1949 received Professional Engineers License in New York. At present going to Brooklyn Poly for Doctorate degree and has taught thermodynamics in the evening session. Has published several articles on properties of gases, thermodynamics and applied mechanics. Present duties are as assistant to the Contract Manager of the Nuclear Energy Department.

In a recent paper, R. Hicks has published an analysis of an Annular plate, simply supported and carrying a concentric lateral load distributed around the opening. The physical plate under analysis can be likened to a circular bulkhead or closure. In his paper, Hicks develops equations for the stresses and deflections in such a plate and compares the material economics in using a reinforced hub. The type of loading discussed in the Hicks paper represents the type of loading that can be applied by mechanical application. In this paper, the writer has extended the analysis given in the English paper to the case of such a structure under uniform or hydrostatic type of loading. The analysis given here is quite general (with one exception that will be discussed later in this work) and can be extended to plates having other types of loading and boundary conditions. As such, it is a very powerful method of analysis.

In Figure 1, a cross-section of the plate under discussion is shown with the loading and method of support. It can be shown that the general form of the differential equation representing the deflection surface is given by Equation (1):—

$$\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dw}{dr}\right)\right]=\frac{Q}{D} \quad \ldots\ldots (1)$$

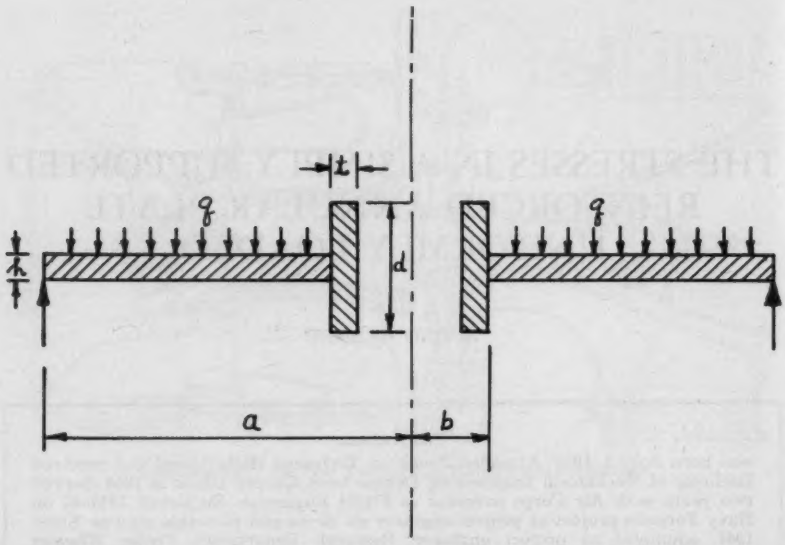


Figure 1. Annular plate supported at the edge, carrying a uniformly distributed load over the surface of the plate.

This corresponds to Equation (57) in Timoshenko's "Plates and Shells" and is also given in "Theory of Elasticity" by Timoshenko and Goodier and "Mathematical Theory of Elasticity" by Love. The solution of Equation (1) for any particular case consists of a general solution with proper boundary conditions placed into it. Instead of using such a solution, the writer has chosen to use superposition. It is shown in Timoshenko's "Plates and Shells" that it is possible in cases such as this to add deflections for several cases to obtain the deflection of a composite case. We start with the case of the unpierced, unreinforced simply supported plate and build from here to the case in question. The steps are given in sequence below and correspond to the loading shown in Figure 2.

1. Deflection of the unpierced plate.
2. Add to (1) the deflection produced by an edge moment of:

$$\frac{q}{16}(3 + v)(a^2 - b^2) \ldots\ldots\ldots\ldots \text{Timoshenko, "Plates \& Shells," Page 67.}$$

3. To the sum of (1) + (2) above, subtract the deflection produced by an edge load of:

$$\frac{qb}{2} \ldots\ldots\ldots\ldots\ldots\ldots \text{Timoshenko, "Plates \& Shells," Page 67.}$$

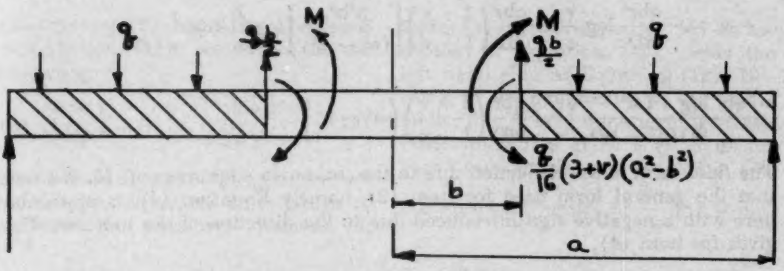


Figure 2. Loading diagram for plate shown in Figure 1.

4. To the sum of steps (1) + (2) + (3) above, we note that there is an additional edge moment introduced due to the reinforcing hub.
Quantitatively, each item can be expressed mathematically. Thus for item (1),

$$w = \frac{q(a^2-r^2)}{64D}\left[\left(\frac{5+v}{1+v}\right)\ a^2 - r^2\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

(Equation 67, "Plates & Shells")

For item (2),

$$w = \frac{b^2q}{32D}\left(\frac{3+v}{1+v}\right)\left(a^2-r^2\right) - \frac{a^2b^2(3+v)q}{16(1-v)D}\log\frac{r}{a} \quad \ldots\ldots\ldots\ldots (3)$$

This is obtained from the general form for an edge moment:—

$$w = \frac{b^2M(a^2-r^2)}{2(1+v)D(a^2-b^2)} - \frac{a^2b^2M}{(1-v)\,D\,(a^2-b^2)}\log\frac{r}{a} \quad \ldots\ldots\ldots (4)$$

Item (3) is now subtractive so we introduce the negative sign and note that $P=\pi qbr$. Introducing these concepts and definitions, we get:—

$$-w = -\left[\frac{Pr^2}{8\pi D}\left(\log\frac{r}{a}-1\right) - \frac{c_1r^2}{4} - c_2\log\frac{r}{a} + c_3\right] \quad \ldots\ldots\ldots\ldots (5)$$

where:

$$c_1 = \frac{P}{4\pi D}\left(\frac{1-v}{1+v} - \frac{2b^2}{a^2-b^2}\log\frac{b}{a}\right)$$

$$c_2 = -\left[\left(\frac{1+v}{1-v}\right)\frac{P}{4\pi D}\right]\left[\frac{a^2b^2}{a^2-b^2}\log\frac{b}{a}\right]$$

$$c_3 = \frac{Pa^2}{8\pi D}\left(1 + \tfrac{1}{2}\left(\frac{1-v}{1+v}\right) - \frac{b^2}{a^2-b^2}\log\frac{b}{a}\right)$$

Timoshenko's "Plates & Shells" Article 17f

and as previously noted for this case $P=\pi bqr$
Introducing the constants into (5) gives:—

$$-w = -\frac{qbr^3}{8D}\log\frac{r}{a} - \frac{qbr}{4D}\left(\frac{1+v}{1-v}\right)\left[\frac{a^2b^2}{(a^2-b^2)}\right]\log\frac{b}{a}\log\frac{r}{a}$$

$$+\frac{qb^3\log\frac{b}{a}(a^2-r^2)r}{8D(a^2-b^2)} - \frac{qbr}{16D}\left(\frac{3+v}{1+v}\right)\left(a^2-r^2\right) \quad \ldots\ldots (6)$$

The final term is the deflection due to the unknown edge moment M. We note that the general form used for item (2), namely Equation (4), is applicable here with a negative sign introduced due to the direction of the moment. This gives for item (4),

$$w = -\frac{b^2M(a^2-r^2)}{2D(1+v)(a^2-b^2)} + \frac{Ma^2b^2\log\frac{r}{a}}{D(1-v)(a^2-b^2)} \quad \ldots\ldots (7)$$

Adding Equations (2), (3), (6) and (7) gives the desired deflection equation:

$$w = \frac{q(a^2-r^2)}{64D}\left[\left(\frac{5+v}{1+v}\right)a^2 - r^2\right] - \frac{qbr^3}{8D}\log\frac{r}{a} - \frac{a^2b^2}{16D}\left(\frac{3+v}{1-v}\right)q\log\frac{r}{a}$$

$$-\frac{qbr}{4D}\left(\frac{1+v}{1-v}\right)\left(\frac{a^2b^2}{a^2-b^2}\right)\log\frac{b}{a}\log\frac{r}{a} + \frac{qb^3\log\frac{b}{a}(a^2-r^2)r}{8D(a^2-b^2)}$$

$$-\frac{qb}{32D}\left(\frac{3+v}{1+v}\right)(a^2-r^2)(2r-b) - \frac{b^2M(a^2-r^2)}{2D(1+v)(a^2-b^2)}$$

$$+\frac{Ma^2b^2\log\frac{r}{a}}{D(1-v)(a^2-b^2)} \quad \ldots\ldots (8)$$

Equation (8) represents the complete, general form of the deflection for the case under study in this paper. The basic problem is now to evaluate the moment M appearing in Equation (8). It is at this point that we utilize the suggestion made by Hicks and introduce the elementary theory of bending. We follow the Hicks' derivation as follows:—

As it noted on Figure 1, the reinforcement has a rectangular section with its greatest bending stiffness in a radial plane which is perpendicular to the plane of the plate. It is assumed at this point that the radius of the hole is large compared to the width of the reinforcement, for economy of material. Thus, the diameter of the reinforcement measured to the center of its cross-section can be taken as being equal to the diameter of the hole. For an element of reinforcement subtended by the Angle $d\theta$, equilibrium considerations give:

$$\eta = bM \quad \ldots\ldots (9)$$

If it is taken that the deflection of the plate is small and there is no discontinuity at the juncture of the reinforcement of the plate, then the angle of rotation of the reinforcement must equal the slope of the plate at r=b. Thus, the maximum strain (top and bottom) of the hub is given by Equation (10) with the negative sign due to the negative slope.

$$\varepsilon = -\frac{d}{2b}\left(\frac{dw}{dr}\right)_{r=b} \quad \ldots\ldots (10)$$

From elementary bending theory, we can also write—

$$\varepsilon = \frac{6\eta}{td^2E} \quad \ldots\ldots (11)$$

Substituting (9) and (10), and for E in Equation (11), we arrive at the following:—

$$\left(\frac{dw}{dr}\right)_{r=b} = -\frac{Mh^3b^2}{td^3D(1-v^2)} \quad (12)$$

Equations (8) and (12) give us two independent equations from which to evaluate the unknown moment M.

Differentiation of Equation (8) as indicated in Equation (12) yields the left hand side of Equation (12). Because of the complexity of the arithmetic, this is best done term by term. Performing this at r=b gives us for each term as given in Equation (8), the following values of $\frac{dw}{dr}$ @ r = b.

$$\text{Term (1)} \quad -\frac{qb}{16D}\left[a^2\left(\frac{3+v}{1+v}\right)-b^2\right]$$

$$\text{Term (2)} \quad -\frac{qb^2}{8D}\left[1+3\log\frac{b}{a}\right]$$

$$\text{Term (3)} \quad -\frac{q(3+v)(a^2b)}{16(1-v)D}$$

$$\text{Term (4)} \quad -\frac{qb}{4D}\left(\frac{1+v}{1-v}\right)\left(\frac{a^2b^2}{a^2-b^2}\right)\log\frac{b}{a}\left[1+\log\frac{b}{a}\right]$$

$$\text{Term (5)} \quad \frac{qb^3\log\frac{b}{a}(a^2-3b^2)}{8D(a^2-b^2)}$$

$$\text{Term (6)} \quad -\frac{qb}{16D}\left(\frac{3+v}{1+v}\right)(a^2-2b^2)$$

$$\text{Term (7)} \quad \frac{b^2M}{D(1+v)(a^2-b^2)}$$

$$\text{Term (8)} \quad \frac{Ma^2b}{D(1-v)(a^2-b^2)}$$

If these terms are consolidated and placed into Equation (12), we arrive at the necessary and desired expression for the moment M:—

$$M = q\left[(2a^2-b^2)\left(\frac{3+v}{1+v}\right)+6b^2\log\frac{b}{a}+a^2\left(\frac{3+v}{1-v}\right)\right.$$
$$\left.+\frac{4(1+v)a^2b^2}{(1-v)(a^2-b^2)}\log\frac{b}{a}\left(1+\log\frac{b}{a}\right)-\frac{2b^2\log\frac{b}{a}(a^2-3b^2)}{a^2-b^2}\right]$$
$$\div 16\left[\frac{h^3b}{td^3(1-v^2)}+\frac{b^2}{(1+v)(a^2-b^2)}+\frac{a^2}{(1-v)(a^2-b^2)}\right]\ldots\ldots(13)$$

Equation (13) with Equation (8) gives the final solution for the deflection of the plate under question.

The maximum stress in the reinforcing ring is given as Equation (14) with the M from Equation (13)—

$$S_{ring} = \frac{6Mb}{td^2} \quad \ldots\ldots (14)$$

In order to obtain the stress in the plate, it is necessary to evaluate the radial and tangential moment in the plate. The general form for these moments is:—

$$M_t = -D\left(v\frac{d^2w}{dr^2} + \frac{dw}{r\,dr}\right) \quad \ldots\ldots (15)$$

$$M_r = -D\left[\frac{d^2w}{dr^2} + \frac{v}{r}\frac{dw}{dr}\right] \quad \ldots\ldots (16)$$

From equation (8), $\frac{dw}{dr}$ can be evaluated. This was done before, when M was evaluated at $r = b$.

$$\frac{dw}{dr} = \frac{-qr}{16D}\left[a^2\left(\frac{3+v}{1+v}\right) - r^2\right] - \frac{qbr^2}{8D}\left[1 + 3\log\frac{r}{a}\right]$$

$$- \frac{qb}{4D}\left(\frac{1+v}{1-v}\right)\left(\frac{a^2b^2}{a^2-b^2}\right)\log\frac{b}{a}\left[1 + \log\frac{r}{a}\right] - \frac{q(3+v)a^2b^2}{16D(1-v)r}$$

$$+ \frac{qb^3\log\frac{b}{a}(a^2-3r^2)}{8D(a^2-b^2)} - \frac{qb}{16D}\left(\frac{3+v}{1+v}\right)(a^2 - 3r^2 + br) + \frac{b^2Mr}{D(1+v)(a^2-b^2)}$$

$$+ \frac{Ma^2b^2}{D(1-v)(a^2-b^2)r} \quad \ldots\ldots (17)$$

The second derivative $\frac{d^2w}{dr^2}$ can be evaluated by differentiating Equation (8) and (17) once again. This yields the following expression:—

$$\frac{d^2w}{dr^2} = -\frac{q(a^2)(3+v)}{16D(1+v)} + \frac{3qr^2}{16D} - \frac{5qbr}{8D} - \frac{3qbr}{4D}\log\frac{r}{a}$$

$$- \frac{qb}{4D}\left(\frac{1+v}{1-v}\right)\left(\frac{a^2b^2}{a^2-b^2}\right)\frac{\log\frac{b}{a}}{r} + \frac{qa^2b^2}{16D(r^2)}\left(\frac{3+v}{1-v}\right) - \frac{3qb^3\log\frac{b}{a}}{4D(a^2-b^2)}$$

$$+ \frac{3qbr}{8D}\left(\frac{3+v}{1+v}\right) - \frac{qb^2}{16D} + \frac{b^2M}{D(1+v)(a^2-b^2)} - \frac{Ma^2b^2}{D(1-v)(a^2-b^2)r^2} \quad \ldots\ldots (18)$$

At any particular point, we may evaluate the maximum stress in the plate as:—

$$S_{max} = \frac{6M_{max}}{h^2} \quad \ldots\ldots (19)$$

Thus, we have established by Equations (8) and (13) the deflection of the plate at any point. Equation (14) gives us the stress (max.) in the ring and Equation (15), (16), (17), (18) and (19) allow us to evaluate the stresses in the plate. As such, the problem has been solved.

Since both the first and second derivatives of the deflection are functions of the moment (radial) at the reinforcement, which in turn is a function of the loading and dimensions of the reinforcement, we cannot give a specific solution for the maximum stresses in the plate. It is necessary to calculate M_t and M_r for each case or set of physical conditions to determine the maximum values.

The point which was indicated earlier as being in question (other than the assumptions usually made in this type of problem), is the assumption that the angle between the reinforcing ring and the plate remains constant. For small deflections and a comparatively thin ring, this assumption should be of sufficient accuracy. In order to fully establish this angle accurately, a very extensive analysis is necessary. At present, Mr. DeMarinis of the Nuclear Energy Department of Foster Wheeler Corporation is making such an investigation and his results should be available in the near future. His preliminary calculations indicate that the results of this paper should be satisfactory for most cases of technical importance.

The writer wishes to thank Mr. L. DeMarinis of Foster Wheeler Corporation, Nuclear Energy Department, for his kindness in reviewing the manuscript and Mr. John Cartinhour, Chief Engineer and Manager of the Nuclear Energy Department of Foster Wheeler Corporation for permission to publish this paper.

NOMENCLATURE

a=Outside radius of plate.
b=Inside radius of plate.
t=Thickness of ring.
d=Height of ring.
h=Thickness of plate.
r=Radius to any point in plate.
v=Poissons ratio.
E=Modulus of Elasticity.

$$D=\frac{Eh^3}{12(1-v^2)}$$

$$\epsilon=\text{Strain}=\frac{\text{increase of radius of fibers of ring.}}{\text{original radius of fibers}}$$

w=Deflection of plate.
M=Moment at junction of ring and plate.
M_t=Tangential moment in plate.
M_r=Radial moment in plate.
η=Bending moment acting on a cross-section of the plate.
Q=Shearing force per unit length of cylindrical section of radius r.
P=Total shear load at a point.
q=Unit pressure load on plate.
C_1, C_2 & C_3=Constants of integration.
S=Stress.
S_{ring}=Maximum stress in ring.
S_{max}=Maximum stress in plate.

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ERRATA

In an earlier article by this same author, "The Stresses, Strain and Displacements in a Sphere," by Irving Ganet, starting on page 393 of the issue of the JOURNAL for May 1954 the following errors were printed:

on page 395:

5th line in left hand column below equation (9)—"non-zero" should be "zero."

The equation (10) just below this should be:

$$r^2\frac{d^2u}{d^2U}+2r\frac{dU}{dr}-2U=O \qquad (10)$$

On page 397:

equation 23 should be:

$$\sigma_r=P_i\frac{r_i^3}{r^3}\left[\frac{r_i^3-r_0^3}{r_i^3-r_0^3}\right] \qquad (23)$$

POWDER METALLURGY

ACKNOWLEDGEMENT

A two-day symposium organized by the Council of the Iron and Steel Institute, in association with the Institute of Metals, was held in London on 1 and 2 December 1954, to survey advances made in powder metallurgy since 1947. Fifty papers were included, and this staff article reprinted from the 31 December 1954 issue of *Engineering* summarizes these papers.

1.—MANUFACTURING, PROPERTIES AND TESTING OF POWDERS

The availability of adequate supplies of raw materials of the right quality is a vital matter to existing and potential manufacturers of sintered components. Dr. W. D. Jones (Powder Metallurgy, Limited), in an authoritative review "Metal Powders for Engineering Purposes," describes methods of manufacturing powders for application in engineering components and discusses the relative properties of the powders on the basis of (i) iron, (ii) ferrous alloy, (iii) non-ferrous powders. Although a number of new principles have been applied in manufacture, the most striking developments since 1947, comprise cheaper methods of making base-metal powders, since the price of metal powders sets a restricting limit to the development of powder metallurgy. Some of these developments involve no more than improved "house keeping" but it is significant that new methods have emerged for producing powder as an end product in the process of extracting a metal from its ore.

IRON POWDERS

Large-scale ferrous powder metallurgy has been internationally dependent for its raw material on sponge-iron powder made by the Höganäs Company in Sweden, but new competitive methods have arisen since the war of 1939–1945. To obtain some idea of the scale of operation in the United States in the manufacture of sintered engineering components, the total consumption of iron powder in 1953 was about 11,500 tons, 7,000 tons (probably mainly Swedish sponge-iron) being imported, and the remainder of 4,500 tons being manufactured by the American Companies (Pyron, Plastic Metals, the Easton Metal Powder) and one Canadian Company (Ferrum).

Swedish sponge powder is produced

in the Höganäs process by the reduction of magnetite concentrates packed in ceramic containers, using a mixture of coke or anthracite breeze and coal dust as a reducing agent. The Company have access to relatively pure magnetite concentrates, have their own coal and coke supplies, and manufacture ceramics. The powder finds wide application because (1) it is relatively pure, (2) it is porous and possesses good pressing characteristics, (3) it is cheap to manufacture. Since 1947, newer grades, believed to be prepared by treating the normal powder with hydrogen, and possessing improved properties, have been introduced. In order to better supply the United States market, the Höganäs Company have recently completed a new plant with an initial capacity of 30,000 tons per annum at Riverton, New Jersey.

"RZ" Atomized Iron Powder was developed by Dr. Naeser of Mannesman Röhren Werke about 1942. In the United States, this process has been recently adopted in a new plant erected by the Easton Metal Powder Company, Pennsylvania. Liquid cast iron, low in sulphur and silicon, is atomized and dried in the course of which the powder becomes oxidized. The process is controlled in such a manner that enough carbon occurs in the iron to reduce the oxides present during subsequent heating, so that a relatively low-carbon pure-iron powder is obtained.

The Ferrum process consists in heating together high-carbon powder and iron oxide. The product is a mixture of particles of high density and low microporosity with particles of low density and high microporosity. Details of the physical properties of the powders are not available.

Selected mill scale is reduced in the Pyron process by means of hydrogen. This powder is popular in the United States, and has the advantage of developing slight shrinkage when mixed or infiltrated with copper — for this reason it is frequently mixed with other iron powders for the purpose of reducing expansion.

A reduction process involving carbon and hydrogen in consecutive stages of reduction is used by the Plastic Metals Division of the National Radiator Company, Johnstown, Pennsylvania. This grade of powder finds some acceptance in the United States. An electrolytic grade is produced economically by the same company and, as well known, is particularly suited for the manufacture of high-quality sintered components, especially those of high density and high strength by the technique of double pressing and sintering. In Europe, the principal producer of electrolytic iron is the Husqvarna Vapenfabrik, Sweden, and the material is used by them for a substantial production of high-tensile components based on a technique of double pressing and sintering. The product is very pure and results in low die-wear and compacts of high green strength.

In the United Kingdom, Swedish sponge iron is marketed by Powder Metallurgy, Limited, and both atomized and electrolytic iron are manufactured by the New London Electron works and electrolytic iron will also be manufactured by the Plessey Company under license from the Husqvarna Organization. Data on the mechanical properties of compacts prepared from some of these typical powders have been collated (Table I) from various parts of Dr. Jones' paper.

It will be seen that low-density components would possess a tensile stress of about 13,000 lb. per square inch and an elongation of 5.5 per cent., whereas high-density parts produced by a double-cycle technique and consequently more expensive, would be

much stronger with a tensile strength of 37,000 lb. per square inch and an elongation of 21.5 per cent. One point is outstanding. No one powder is acceptable for all engineering applications and selection is often governed by local or national interests. From the numerous recipes known to be used in industrial manufacture, it is obvious that even a powder metallurgist still likes to back his own fancy.

FERROUS-ALLOY POWDERS

Much interest has been centered on obtaining alloy powders, suitable for admixture with stock iron powders for the manufacture of strong low-alloy content compacts or for alloy parts for high-temperature application.

The hydride process has been used for preparing nickel-chromium alloys by reduction of the mixed oxides with calcium hydride. Stainless-steel powder produced by chemical disintegration is described in a paper by Dr. P. Marshall (Metal and Plastic Compacts, Limited). One of the most important developments since the war has been the production of ferrous alloys by atomization, in the United States, by the Vanadium-Alloys Steel Company, and in the United Kingdom by Powder Metallurgy, Limited.

Vanadium Alloy Steels Company make several standard grades of stainless-steel powders corresponding to A.I.S.I.302B, 316, 318 and 431. Most of these powders (minus 100 mesh) if pressed at 80,000 lb. per square inch and sintered for 45 min. at 1,230 deg. C. give compacts with tensile strengths of 30,000 to 40,000 lb. per square inch and elongations of 5 to 15 per cent. Re-pressing at 80,000 lb. per square inch and re-sintering at 1,230 deg. C. improve the tensile strengths to 55,000 to 65,000 lb. per square inch

TABLE I.—Mechanical Properties of Powder Compacts

Process	Grade	Compacting pressure, lb. per sq. in	Density after compacting, grams per c.c.	Properties after sintering for 1 hour			Sintering temp. deg. C.	No. of and sintering compacting cycles	Apparent density, grams per c.c.
				Density, grams per c.c.	Tensile strength, lb. per sq. in.	Elongation, per cent.			
Höganäs	M 100	60,000	5.80	5.85 6.55	13,000 23,000	5.5 13.5	1,100 1,100	One Two	—
	M.H	60,000	6.25	6.20 6.50	16,000 24,000	5.5 14.5	1,100 1,100	One Two	—
	Ancor 80 (Riverton U.S.A.)	60,000 —	6.20 —	6.25 6.20	— 20,000	— 8	— —	One —	—
Easton	R.Z. Type	60,000	6.3	—	18,000-19,000	7	1,120		2.4
		100,000	—	—	23,000-29,000	7			
Ferrum	—	—	No details available				—	—	2.8-3.0
Pyron	—	50,000	5.86	—	12,500	5.25	—	—	—
		100,000	—	—	22,500	7.25	—	—	—
National Radiator	Reduced and electrolytic	—No details given							
Husqvarna	Standard	60,000	6.7-6.8	—	18,500	5	1,050	One	—
		85,500 (1) and 60,000 (2)	—	—	35,600	28	1,050 (1) and 1,250 (2)	Two	—
	Sponge	60,000	6.4-6.6	—	25,600	13	1,050	—	—
		85,500 (1) and 60,000 (2)	—	—	37,000	21.5	1,050 (1) and 1,250 (2)	—	—

and the elongation to 12 to 24 per cent. The best physical properties were obtained with a stainless steel, 318 Si (Cr-Ni-Mo-Nb-Si), which showed a tensile strength of 92,000 lb. per square inch and an elongation of 36 per cent. These powders have been used not only for engineering components but also for filters and as a raw material for the manufacture of stainless-steel flake powder.

In "Powders for Magnetic Applications," Mr. G. R. Polgreen (Salford Electrical Instruments) considers that electrolytic, carbonyl and sponge-iron powders provide most of the basic material used for electrical applications. For these, the magnetic requirements may be one of the following: (i) low loss at low flux density, as for telephony and radio cores; (ii) low loss at high flux density, as for pole pieces, transformers and armatures for motors; and (iii) high hysteresis loss, as for permanent magnets of all kinds.

The first group mainly requires low eddy-current loss, which involves the use of finer powders as the operating frequency is increased; the second requires low hysteresis loss and an insulated coarse powder will generally give a core with negligible eddy-current loss at the lower-power frequencies; in the last group, the object is to store the maximum energy in a given volume and a figure of merit of a permanent magnet is the energy factor which is a measure of the hysteresis loss. This is a product of B and H in the second quadrant ($BH_{max.}$) the units being gauss and oersted, respectively.

The coercive force is critically dependent on the particle size of the powder from which the magnets are made. A powder of pure iron with a particle size of 0.01 to 0.02 micron will have a coercive force of 1,000 oersteds and if it is pressed, this value will be halved approximately but the remanence will be increased to about 5,000 gauss. It is shown how it is possible with pure iron, classically a low-loss metal, to make either low-loss cores or permanent magnets depending upon the particle-size grouping.

The general characteristics of electrolytic carbonyl, sponge powder, oxide-ferrites powders for low-loss applications are discussed. The hydrogen reduction of single or mixed oxides or salts is the only material that can be used to produce on a commercial scale nearly all metallic magnetic powders in any required size grading; a plant is described which has operated 14 years for producing iron and magnetic-alloy powders for manufacture into a great variety of telephone and radio cores. Details of the production of iron or alloy micro powders are also included. The advantages of micropowder magnets, as compared with other types, are: (i) lighter weight; (ii) generally lower cost using iron micropowder; (iii) ability to drill, machine and shape the pressed magnets; (iv) ability to mould intricate shapes to accurate dimensions; (v) economy of strategic and expensive metals such as cobalt; (vi) control of remanence-coercivity over a wide range and accurate control of magnetic properties in production; (vii) great uniformity of density throughout a pressing, which is especially important for parts rotating at high speed and also instrument magnets; and (viii) the low-temperature molding method permits the incorporation of inserts or the simultaneous pressing of different kinds of powder. Future developments will be the preparation of oriented cores or magnets which will require shaped particles. If elongated particles could be made with a minimum dimension of domain size and a maximum five times as large, and if such powders could be oriented within a magnet by pressing to 50 per cent theoretical

density, theoretical considerations show that pure-iron micropowder magnets could be made with a coercive force of 3,000 to 5,000 oersteds and a remanence of 5,000 to 16,000 gauss. Powder metallurgy thus possesses considerable scope for developing magnetic materials.

NON-FERROUS METAL POWDERS

Though expansion has occurred in the manufacture of reduced and electrolytic copper or atomized alloys, few new technical or scientific developments have been made. It is understood that plants for the manufacture of atomized aluminum have been installed in Britain by the British Aluminum and the Northern Aluminum Companies. The manufacture of atomized brass powder with an irregular particle shape has been useful; this has resulted in better green strength in the compact and has contributed to increased production of brass components.

In recent years, a development of outstanding interest has occurred in hydro-metallurgical extraction of metals, some in the form of powders, from their ores. The most important of these, the Chemical Metals Process, depends upon the general principal of dissolving a concentrate of scrap metal with suitable acids or alkalis, purification of the solution and finally precipitation of the pure powdered metal using either hydrogen or carbon monoxide at elevated temperatures or pressures. Two plants in Canada and one in the United States are in production or being erected: one is designed to produce 2,000 tons of cobalt powder a year; another will produce annually 700 tons of cobalt powder, 900 tons of nickel and 700 tons of copper, as well as 7,500 tons of ammonium sulphate; the third, a nickel refinery, is designed to produce every year 8,500 tons of nickel powder, 1,000 tons of copper, 150 tons of cobalt and 70,000 tons of ammonium sulphate. A number of plants are being erected under license to the Chemetals Corporation, of New York, for refining copper and brass scrap and refinery by-products. This Corporation is extensively promoting development of techniques for the direct rolling of powder into sheet and strip and copper-powder extraction plants will probably operate in conjunction with rolling plants manufacturing copper sheet. Dr. Jones concludes that these new activities which he terms "Powder Extraction Metallurgy" and "Continuous Powder Metallurgy" are developing simultaneously.

The fabrication of tantalum is described by Mr. R. Titterington and Mr. A. G. Simpson (Murex, Limited) and users will find useful information in their paper on rolling, swaying, wire-drawing, annealing, deep-drawing, welding, and machining the metal. Tantalum combines readily with oxygen and nitrogen and must be mechanically worked at room temperature. The rate of work-hardening for tantalum is very low and therefore considerable cold work can be undertaken before annealing becomes necessary. The metal can be single-sheet rolled down to 0.010 in. thick, but sheets down to 0.002 in. thick can be produced by pack-rolling two sheets from 0.02 in. Recently, foil production has become necessary and thicknesses down to 0.0001 in. are now obtained in a cluster mill. The economic limit for tantalum foil is 0.0005 in. Tantalum bars are swaged and then drawn to wires with a minimum thickness of 0.004 in. The annealing of tantalum is difficult, since it is so reactive towards residual furnace gases; all material is wrapped in tantalum sheet or placed in a box with a tight-fitting lid. Cold-worked sheet or wire is annealed when hardness values of 170 to 190 (D.P.N.) have been developed.

TESTING OF POWDERS

Developments in testing metal powders, reviewed by Mr. G. R. Bell (Powder Metallurgy, Limited) have been confined to improvements in existing apparatus, though extensive work has been done to assess the magnitude of errors in various tests and correlating results obtained from different methods. American standards are increasing in importance in a widening field. Notable work has been undertaken on the automatic counting and sizing of particles. The review is divided into sections dealing with work on particle shape, particle density, the surface condition of particles, size distribution, sieve testing, counting using a light microscope, sedimentation, centrifugal analysis, elutriation, turbidimetric analyses, permeability measurements, surface absorption, and miscellaneous methods.

An instrument, described in "Application of Particle Size Analysis to the Quality Control of Metal Powders," by Mr. V. T. Morgan (Bound Brook Bearings, Limited), has been found particularly useful in the United Kingdom and America for determining, on a routine basis, the comparative particle-size distribution of metal powders. The instrument based on principles of sedimentation and photo-extinction turbidimetry employs autographic recording and a complete sub-sieve analysis can be made in about 20 minutes.

2.— PRINCIPLES AND CONTROL OF COMPACTING AND SINTERING

An account is given of some properties of filter elements by Mr. V. T. Morgan (Bound Brook Bearings, Limited). The degree of interparticle welding produced during sintering is related to its effect upon mechanical

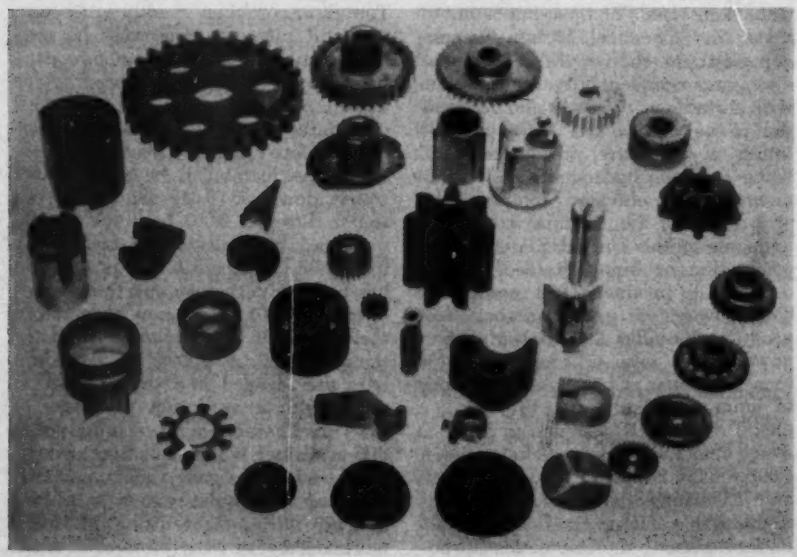

Figure 1. Examples of the range of engineering products made in the United States during 1953 by the sintering process from metallic powders.

strength, porosity, permeability and pore-size. An improvement in strength is shown graphically to be obtained at the expense of permeability. Consequently, in practice, a compromise between these two opposing factors is essential. It is shown that efficiency of filtration depends on the relationship between the sizes of the sediment particles and those of the pores of the filter. A useful relationship is given for the pore size and permeability of a range of ceramic and metal filters.

A laboratory investigation on the relationships between the properties of iron powders and powder compacts is described by Professor F. V. Lenel (Rensselaer Polytechnic), Mr. H. D. Ambs (Frankford Arsenal) and Mr. E. O. Lomerson (Pratt and Whitney Aircraft Corporation). Although no attempt was made to produce in the laboratory powders which would meet the requirements of commercial powders, some of the conclusions of the investigation should be of assistance, according to the authors, in controlling the methods for producing commercial powders in such a manner that they would yield higher-strength compacts. Increasing the temperature of reduction of oxide for the manufacture of powder and also the severity of comminution both make the powder particles smoother and less irregular. Such changes in surface configuration result in lower tensile strengths of the pressed and sintered compacts. The compressibility of the powders increases with increasing temperatures of reduction and more severe methods of comminution. Micrographs illustrate that comminution of the sponge powder is most severe after wire brushing and becomes less severe progressively in a mortar and pestle, disc milling and hammer-milling respectively.

Considerable interest has been aroused in recent years by development work in Germany on the direct production of metal sheets on a pilot-plant scale from powders. The results of an investigation, the first which seems to have been prepared by an independent authority, and for that alone it is particularly welcome, are reported by Mr. P. E. Evans and Mr. G. C. Smith (Cambridge University). Copper powder was compacted by direct rolling in a standard two-high rolling mill to produce a continuous length of metal strip, and data were sought on the influence of rolling pressure combined with standard sintering conditions with varying time and temperature. The powder, contained in a hopper, was fed to the rolls by means of an inclined shute. The feed rate, controlled by the aperture of the hopper and inclination of the shute, was not critical provided that enough powder was always present at the roll gap to ensure a continuous supply for compaction. The width of strip was limited by the width of the feeding shute, though this could be raised very nearly up to the absolute limit of the barrel length of the roll. The rolling mill consisted of a two-high stand with 8-inch diameter rolls driven at 24 r.p.m. by a 25 h.p.-electric motor. Metal powder is fed into one side of the mill and issues horizontally as compacted strip on the other. The strip thickness can be varied within narrow limits by varying the roll gap from that size at which the strip is just strong enough for subsequent handling to that size obtained when the rolls are initially pressed tightly together. The maximum thickness of strip which can be produced sufficiently strong to be handled appears from previous investigations to increase almost linearly with the roll diameter. Other factors such as roll speed, and powder-particle size will also affect the thickness. Strip with good edges is produced in conjunction with guides used in the roll gap to restrict lateral flow.

Electrolytic copper powder was used throughout the investigation as the

most suitable material since the powder, possessing good compacting properties and a wide range of particle shapes and sizes, is readily available. It is clearly shown that the roll gap critically influences the mechanical and physical properties of the strip: the maximum green density, but not that after sintering at 1,000 deg. C. for two hours, occurs at the minimum roll gap; the thickness of both green and sintered strip decrease non-linearly with diminishing roll gap; the maximum strength, about 18 Kg. per square millimeter ultimate tensile strength, and elongation of about 15 per cent are obtained at low but not the minimum roll gap and correspond to the point of maximum sintered density, namely, 8.1 grams per cubic centimeter.

After the effect of different rolling conditions had been established, strip was rolled to a uniform green thickness of 0.60 mm. and sintered under various conditions. The ultimate tensile strength, percentage elongation and density of green strip increase markedly in the first 60 minutes of sintering at 1,000 deg. C., after which a gradual increase occurs up to the maximum time. The same properties show a slow increase with two hours of sintering up to 750 deg. C. and a more rapid increase up to about 1,000 deg. C. The maximum values obtained in these two series were ultimate tensile strength, 9.5 Kg. per square millimeter, elongation, 8 per cent, and density, 7.0 grams per cubic centimeter. Strip which had been rolled to a green thickness of 0.60 mm. and sintered for 130 minutes at 1,000 deg. C. was cold rolled to thickness reductions ranging from 8 per cent to 67 per cent, and annealed for 1 hour *in vacuo* to promote recovery. Transverse cracks appeared at the edges with deformations greater than 50 per cent. Cold-rolling produces a marked improvement in properties, the following maximum values being obtained at 47 per cent to 50 per cent deformation: ultimate tensile strength, 27 Kg per square millimeter, elongation, 33 per cent, and density 8.78 grams per cubic centimeter. No attempt is made to consider the economic aspects of this process, but the commercial possibilities have already been referred to in the paper by Dr. W. D. Jones.

Sintering-furnace atmospheres for industrial practice are reviewed by Mr. L. D. Brownlee, Mr. R. Edwards and Mr. T. Raine. The considerations involved in choosing a suitable atmosphere include the effect of the atmosphere on the metal, on the oxide of the metal, on compounds such as carbides of the metal and on furnace refractories.

3.—MANUFACTURING AND PROPERTIES OF STRUCTURAL ENGINEERING COMPONENTS

The scale of American and European production of some engineering parts is assessed in a comprehensive paper by Mr. C. J. Leadbeater (Armament Research Establishment). Production data are quoted for America, Italy, France, Germany and Great Britain, and it is significant that developments have occurred in variety and scale of production in numerous countries. In the United States the use of iron powder in bearings and parts in 1953 was 7,500 tons as compared with 3,000 tons in 1948. Copper-powder production for self-lubricating bearings, mechanical parts and friction materials amounted to nearly 12,000 tons in 1953, almost double that used five years previously. The total consumption in Italy is estimated to be 700 tons per annum for iron, steel and copper infiltrated parts which are used for automobile shock-absorbers, cages for ball bearings, suspension bearings, parts for meters, motor cycles and textile machinery. In France, the second year of production was 1953, when nearly 600 tons of iron and copper powders were used. The

1954 production of parts in Germany is estimated to be 1,100 tons as compared with 300 tons in 1949. A two-fold increase in parts production has recently occurred in the United Kingdom, 550 tons of iron and 900 tons of non-ferrous powders (mainly copper, brass, bronze) being used in 1954.

The scope of application of sintered parts in the United Kingdom may be judged from the following. In one plant, 300 parts mainly iron base were currently in production and were being used in the following proportions: 21 per cent. for motor-cycle parts (fork bushes, thrust and chain-wheel washers, gear-box brushes); 11 per cent for motor-car parts (bushes, thrust washers, door-lock parts); 3 per cent for cycle components (handlebar and brake-lever washers, hub gears); 18 per cent for gun components (magazine catches, triggers, sight-locking bolts); 5 per cent for electric motors (pole pieces); 12 per cent for miscellaneous textile components; 30 per cent for miscellaneous engineering parts.

The variety of shape and size of current sintered engineering components are illustrated in Fig. 1. Technical developments in materials have been gradual and existing data confirm that ferrous parts form 60 per cent of the total production. The strength of ferrous parts has been improved by the use of several methods. (1) The powder mixes consist of iron with copper, nickel or carbon. Copper is now universally used for improving the strength of parts and, in the United States, the usual content ranges from 2 per cent to 7.5 per cent. Data are collated for fine iron powders mixed with up to 10 per cent. copper and processed differently resulting in ultimate tensile strength, depending also on the density of the compact, from 8.6 tons per square inch (low density) to 38 tons per square inch (high density). The addition of nickel up to 20 per cent in an iron-powder mix results in an increased tensile strength of up to 45 tons per square inch in the sintered compact. The inclusion of carbon in the iron-nickel mix produces significant changes in properties in alloys of intermediate nickel contents; as the carbon content was increased up to 1 per cent, a lower nickel content was required to produce the maximum strength in a given series of alloys. The manufacture of components such as rifle magazines, catches, triggers and cycle-hub gears, from iron containing 5 per cent nickel has increased in the United Kingdom and the average properties, depending on nickel content and processing, are:—ultimate strength, 26-32 tons per square inch; Brinell hardness 120-180; elongation, 6-12 per cent; and density 7.0 grams per cc. Cyanide hardening or chromium plating can be applied to such components to develop wear-resistant surfaces.

A porous matrix such as iron may be infiltrated with molten copper or bronze in order to improve its strength or wear resistance, especially when the infiltration process is followed by carburizing. (By infiltration is meant the preliminary production of a porous skeleton by sintering a high-melting metal and afterwards filling the pores of the skeleton with a low-melting metal, the latter being termed the infiltrant metal). Dense or nearly fully-dense material is obtained in this way and the mechanical strength is substantially improved by the elimination of the notch effect existing in the periphery of individual pores. Iron matrices with porosities ranging from 25 per cent to 10 per cent were infiltrated to various degrees up to 100 per cent theoretical density and developed tensile strengths ranging from 14.2 tons per square inch to 45.4 tons per square inch. A considerable amount of copper infiltration is carried out in the United States using a bronze containing iron which is deliberately added to mini-

mize the dissolution of iron at the surface during infiltration. A recent addition to large-scale techniques in the United States has been the use of brass instead of bronze for infiltration since the process occurs more easily and lower working temperatures are required. Leaded cooper-zinc brasses (90/10; 80/20; 85/15) were used. The disadvantages of brass infiltration include the loss of zinc with consequent frequent shut-downs to clean out the furnace or replace the heating elements which have deteriorated.

As a postscript to the manufacture of high-strength parts, Dr. L. Harrison (Sheepbridge Engineering Limited), and Mr. S. Marton (Sintered Products, Limited) describe some experiments on the production of high-strength material and parts by powder metallurgy using the techniques of (1) single sintering and pressing, (2) double pressing and sintering, (3) infiltration of a porous iron skeleton. Generally, for small components with a very high cross-section to thickness ratio and relatively simple shape without varying levels in the direction of pressing, method 2 is ideal for achieving high densities and maximum strength by means of carburization which is effective throughout the thin section; this method is equally important for parts which require ductility and dimensions to close tolerances. Method 1 is the most suitable for parts of intricate shape needing complicated tools, and the dimensions of parts can meet most commercial limits. Where a wide tolerance in dimensions is permitted, infiltration becomes the first choice, since if the need for sizing is eliminated this method is the cheapest of the three. If large parts are required, infiltration is again a good choice, from the standpoint of economy and ease of production.

NON-FERROUS METALS

Sintered-brass parts are growing in importance since the main difficulties such as loss of zinc from the component during sintering, lack of ductility, contamination of the furnace necessitating frequent shut-down for cleaning operations are being brought under control. Recent practice has tended to use brass powder containing intermediate zinc contents to minimize loss. The most widely-used grade contains 78.5 per cent copper, 20 per cent zinc, 1.5 per cent lead and its general acceptance is strongly linked to the improved machinability of the part resulting from the presence of lead—an important advantage for secondary operations such as under-cutting, drilling and threading, all of which can be achieved with normal cutting tools. Data from three sources on the mechanical properties of sintered-brass parts show variations in tensile strength from 15,100 lb. per square inch to 35,000 lb. per square inch and elongation from 3.5 per cent to 48 per cent. The inclusion of 0.3 per cent phosphorus in the brass results in a striking improvement in elongation. Applications for sintered-brass parts include matching governor weights and drive bar, dish-washer timers, pin-tumbler padlocks, lock cylinders for eight different companies, faucet handles, booster rotor fuse components, firing plugs for U.S. Army M 32 percussion primers and compass bezel rings.

FRICTION MATERIALS

Increased production facilities have become available in the United Kingdom during 1954 for making single discs up to 18.5 in. external diameter and segmental discs up to 24 in. diameter from facings of bronze contain-

ing silica, graphite, and lead, diffused to a rigid iron backing plate. These components are used as clutch or brake linings in earth-moving equipment. Four commonly used grades are characterized by low friction (up to 0.15) for wet and dry applications, uniform and fairly low friction (0.2) and high friction (0.4 to 0.5). Sintered friction plates are justified on performance rather than cost and are generally manufactured in simple ring, ring-segment or rectangular shapes.

The work of Mr. E. V. Walker, Mr. R. E. S. Walters (Post Office Engineering Research Station) and Mr. D. K. Worn (Mond Nickel Company) has demonstrated the potentiality of powder metallurgy in the production of high-permeability magnetic alloy strip of Permalloy C or Mumetal (normally 77 per cent. Ni, 14 per cent Fe, 4 per cent Mo and 5 per cent. Cu). The material made by compacting and sintering was found to be superior and more consistent in properties than those of the conventionally produced alloys, and these differences are attributable to the higher purity and closer control of composition achieved in the alloys produced from powder. The maximum magnetic permeability of the cast and rolled alloys (mean 28,000) are obtained after annealing the stock in very pure hydrogen, which is a difficult operation commercially. The powder-metallurgy product can be annealed, however, in wet hydrogen without detriment to give a mean permeability of 30,000. Trials are now in progress under conditions appropriate to commercial production and it is expected that quantity production of high quality strip will be successfully developed.

One of the outstanding exhibits at the Symposium was a group of Fluon (polytetrafluorethylene) impregnated materials. Some important work has been done in the United Kingdom in establishing sintered materials the chief attraction of which is low friction. Sintered copper, for instance, impregnated with solid Fluon, has a coefficient of friction of 0.05 between 15 and 250 deg. C., above which the plastic begins to decompose. The friction coefficient of sintered copper in the same temperature range increases from 0.24 to 0.8, while that of machined copper decreases from 1.3 to about 1.0. Various types of bearings have been designed to take advantage of the promising features of Fluon. Fluon is incorporated in steel-backed sintered lead-bronze bearings by impressing powder or sheet into the bearing surface and heating at 350 to 400 deg. C. at a pressure of 1 ton per square inch until the softened plastic fills the pores to a depth of at least 0.03 in. Fluon-impregnated bushes and thrust bearings, the manufacture of which began about two years ago, possess excellent properties as a dry bearing surface, and field tests have shown them to be widely applicable where lubrication is impossible or undesirable, as in textile and food machinery. Since a lubricant, however, is not used, the speed-load factor for such a material is considerably lower than that of a lubricated bearing. This point should not be over emphasized since the conditions of operation of many types of bearings are not severe and Fluon-impregnated bearings should find wide applications.

Method of preparing and testing fluon-impregnated self-lubricating bearings are described by Dr. A. Blainey (Atomic Energy Research Establishment, Harwell). It was found that these materials would operate dry in corrosive nitric acid solutions or in gasoline, high surface speeds being permissible when a liquid cooling medium was present at the bearing surface.

4.—POWDER METALLURGY OF HIGH-MELTING-POINT MATERIALS

Mr. E. C. Green, Mr. D. J. Jones and Mr. W. R. Pitkin (General Electric Company, Limited) describe developments in heavy alloys of tungsten-nickel-iron. These materials find extensive application for protection against radio activity, for heavy-duty electrical contacts and for mass balancing. Since tungsten is soluble in iron as well as in nickel, the authors devised compacting and sintering procedures for three tungsten (90 to 95 per cent), nickel (7 to 3.5 per cent) and iron (3 to 1.5 per cent) alloys. The results indicated that (i) the density achieved was independent of time and temperature, (ii) in general, tensile strength and elongation increase with sintering time and temperature, (iii) the elongation is greater for the slowly-cooled specimens, and (iv) the elongation decreases with increasing tungsten content. The outstanding quality about some of these alloys is their high elongation which enabled substantial cold rolling to be undertaken. Sintered sheets, measuring 6 in. by 1.5 in. by 0.125 in., could be cold deformed by cross rolling in steps of 60 per cent reduction of cross-sectional area to sheets 18–24 in. long by 2–2.5 in. wide, or 6 in. long by 4–6 in. wide. Intermediate anneals at 1,450 deg. C. were necessary after each 60 per cent reduction in cross-sectional area produced in cold rolling. Such improvements in elongation must undoubtedly increase the range of application of heavy alloys in the engineering field.

Variation in carbon content in standard sintered tungsten-carbide-cobalt is shown by Mr. L. W. Brownlee, Dr. R. Edwards and Dr. T. Raine to produce a marked reduction in the transverse rupture strength. A 0.2 per cent of surplus free carbon will reduce the rupture strength from 90 to 65 tons per square inch and similarly a deficiency of 0.1 per cent carbon will reduce the rupture strength from 90 to 55 tons per square inch. Very rigorous control of the carbon content during manufacture of "hard-metal" tool tips is imperative, since carbon deficiency, although characterized by high wear-resistance, tends to result in cracking and breaking of the tip. In addition, such a hard metal is very liable to develop cracking on brazing and crumbling of the cutting edge during grinding. Mr. Brownlee and Drs. Edwards and Raine are on the staff of the Metropolitan-Vickers Electric Company.

The remaining papers in this group are devoted to materials for high-temperature application and though many data are included, it is unlikely that these materials will find application until their toughness has been improved.

EDUCATION AND RESEARCH FOR THE NATIONS FUTURE

THOMAS K. EWAN and HENRIETTA JACOBSEN

THE AUTHORS

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Mrs. Henrietta Jacobsen is Executive Assistant, Office of Government Sponsored Research, The University of Texas. She has had twelve years of experience in the administration of Government sponsored research in universities. At the close of World War II she was the recipient of the Certificate of Appreciation from the Office of Scientific Research and Development and the Naval Ordnance Development Award.

A few hundred feet from the main tower of The University of Texas within a stone's throw of the shadows of its academic halls exists one of this nation's finest research and development centers, the Defense Research Laboratory of The University of Texas (Figure 1). Secluded among big live oak trees, amid academic serenity, it stands unpretentiously behind a security fence. In the surrounding quiet and nearness of academic pursuits this little publicized but highly important research and development laboratory goes about its daily chores of serving the Military Services of the Department of Defense. Proponents of military unification could profit greatly by spending a few hours studying its work and operation. The Defense Research Laboratory serves the Navy, Air Force and Army. Its projects include many broad fields of research and development, ranging from underwater ordnance to guided missiles; from aircraft detection to aircraft destruction; from safety to countermeasures. On land, in the air, and under the sea, the search for knowledge for basic truths goes on in the extensive facilities of DRL. It was first established in 1945 primarily to serve the Bureau of Ordnance of the Department of the Navy in the solution of scientific problems of Naval Ordnance. However, since 1945 it has broadened its activities to serve all branches of the military.

World War II brought the realization to the nation that many of our best scientific brains were concentrated in the colleges and universities. In 1941 the president of the United States, by executive order, created the Office of Scientific Research and Development for the Armed Services. During 1941-

Figure 1. The Defense Research Laboratory, The Unviersity of Texas.

45, through the Office of Scientific Research and Development, contracts for military research and development were placed with certain large universities, and scientific staffs were recruited from other schools. This was the beginning of large scale participation by civilian groups in cooperation with the military services in research and development in this country. Prior to 1941 the Army and Navy had limited personnel and funds for research and development work and there did not exist a means whereby the services of principal scientists throughout the country could be enlisted on problems of a military nature. With sharply reduced enrollments, many professors were available to apply their talents to weapons research for the military forces. Because of the excellent accomplishments of the university programs, the Navy Bureau of Ordnance toward the end of the war entered into a plan with certain universities to establish a new kind of Government-University relationship: the Government-sponsored *peacetime* military research project.

One of these schools was The University of Texas, whose President and Board of Regents concurred with the plans of the Bureau of Ordnance of the Department of the Navy in this partnership devoted to the future defense of the nation. For both partners there were excellent advantages to the arrangement, although it was initially undertaken with outspoken criticism from many representatives of both government and universities who feared the loss of academic freedom with accompanying government controls and the retarding of normal university basic research in favor of applied development projects. The best answer to these critics is the record of the Defense Research Laboratory of The University of Texas, now going into its ninth year. Devoted entirely to the service of the government, DRL goes about its business of solving military research and development problems while fostering a healthy amount of basic research. Through intelligent coordination with military representatives the work of DRL proceeds in an atmosphere of a true partnership.

Its founder and director, Dr. C. P. Boner,* and the Board of Regents of The University of Texas, recognized with the conclusion of World War II

*Also Vice-President of The University of Texas.

that the problems and needs of the military in the field of research and development had not diminished. It was further recognized that there did not exist within the military establishment sufficient technical and scientific personnel to solve all the problems facing this Nation, nor would it be possible to assemble all the needed talent under the auspices of the federal government. In establishing the Defense Research Laboratory, The University of Texas felt that it had a responsibility in addition to its academic functions to assist the military through research and development in insuring security of this nation.

Research for the defense of the nation today requires that fundamental work and application proceed simultaneously. It is often difficult to determine where one leaves off and the other begins. This is desirable, for the two forms of work tend to cross-pollinate each other and each is stronger for the stimulus of the other. World War II utilized to the utmost the storehouse of basic scientific information. It is important that with the developing of hardware for our defense we replenish our stock-pile of basic scientific knowledge. Such is the work of the Defense Research Laboratory, ranging from basic studies to "fleet hardware" needs.

The Defense Research Laboratory sets a pattern for a new type of laboratory that will be necessary for our defense program as far as we can see into the future. It is the type of applied laboratory which can serve the increasing demands being made for new scientific discoveries. It is the type of university laboratory which can perform certain tasks in the applied field that cannot be done as well in laboratories of either industry or government. This type of laboratory is needed as well as those of industry and government to find answers to the scientific and technical problems intrinsic to the defense of this nation.

The work of the laboratory is divided into three major divisions: the Acoustics Division, the Radar Division and the Aeromechanics Division. The Acoustics Division is concerned with a wide range of underwater mechanisms studies. It is divided into a number of sections to provide research and development in underwater problems ranging from theoretical studies to pilot line models.

Study, design, development and testing of projects in the following fields form a part of the work of the Acoustics Division: hydrodynamics, hydromechanics, machine design, heat transfer, thermodynamics, structures, underwater acoustics detection equipment, electrical devices, mechanical devices, instruments, hydroacoustics filters, transducer systems for flow and pressure studies, shock and pressure wave, geophysics, electromagnetic theory, electronic circuits, electrical networks, the statistical theory of noise, physical and electrochemical phenomena, transistors, miniaturization, semi-conductor electronics, ultrasonics, binaural sound, acoustical absorption, and related subjects. The latest measuring, recording and analyzing equipment is available for these projects. Test facilities including cold room environmental facilities, wind tunnels and material test facilities are employed to provide "fleet simulated conditions." The work is carried on in the main Defense Research Laboratory and at the Lake Travis Field Station, (Figure 2) a floating test and development laboratory with full length test well (Figure 3), transducer mounting test columns, motor driven hoists, machine shop and augmented by Navy picket boats and smaller craft. Because of its large expanse of deep, quiet water, the lake is well suited for basic study of noise, echo ranging, and other problems in sonar and subsurface experimental work. This field station also provides excellent facilities for testing work and

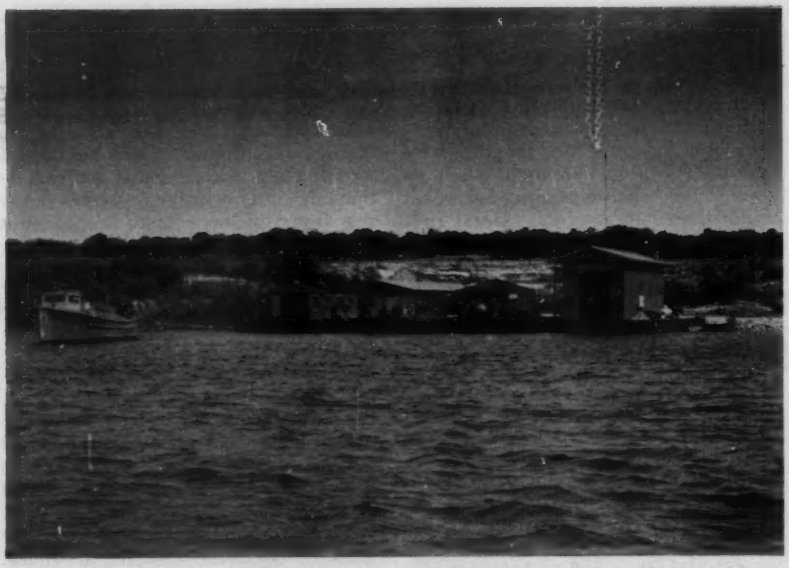

Figure 2. Lake Travis Field Station.

Figure 3. A floating test and development laboratory.

Figure 4. A Radar Field Station.

Figure 5. Radar Division Equipment Room for Guidance Study.

development studies for underwater ordnance.

A Radar Division (Figure 4) has over an extended period been occupied with investigations of theoretical and experimental problems associated with radar guidance and the automatic-tracking capabilities of ground-based radars and missile target-seeking systems.

The experimental work of the Radar Division (Figure 5) includes the evaluation of automatic range-acquisition and range-tracking systems as employed with aircraft; measurement of radar cross-section and target jitter; investigation of methods of pulse-by-pulse data recording and the rapid reduction of data; and pattern measurements with full-scale aircraft targets.

In the laboratory, simulated computer studies and paper analysis have centered about the problem of evaluating the effects of radar noise and tracking errors upon general system performance. Classified projects have been undertaken in the general fields of countermeasures and propagation phenomena.

The Aeromechanics Division work is divided into the following studies:

Figure 6. Wind Tunnels at Balcones Research Center.

boundary layer velocity distribution studies; mechanics of continuous media and high Mach number airflow studies; aerodynamic characteristics of nozzles and diffusers for supersonic wind tunnels; skin friction effects at supersonic speeds; variable Mach number nozzles; design and development of models.

Much of the work of this division is theoretical in nature; however, experimental phases are carried out at the Balcones Research Center field station using two wind tunnels (Figure 6) designated as the "Intermittent Flow Supersonic Wind Tunnel" and the "Continuous Flow Supersonic Wind Tunnel." These serve the Navy and Air Force. They are capable of speeds up to *Mach Number 5 employing †nozzles with test section sizes up to 6" x 6". Plans are underway for a Mach Number 10.0 nozzle for the intermittent flow tunnel. The work of these tunnels includes boundary layer studies of simple bodies such as flat plates, cone-cylinder or ogival bodies of revolution and airfoil sections; skin friction, heat transfer, and other boundary layer characteristics at supersonic speeds; and simulation of heat transfer effects at the high flight speeds of missiles and aircraft. These studies will provide the basic knowledge necessary to an understanding of the phenomenon of aerodynamic heating and to the penetration of the "thermal barrier," the next major obstacle in the battle for increasing flight speeds. Work is also carried out on missile configuration and development of specialized equipment items for missiles. Investigation is also conducted on transient effects in flow studies.

The growth and development of this unique laboratory is of considerable interest. It was initially equipped over 90% from government surplus and excess sources without an exchange of funds, thereby saving the taxpayers tens of thousands of dollars and at the same time making these funds available for research studies. Two important facts played a major role in the equipping and outfitting of this laboratory largely from surplus and excess sources. First, it was recognized that with the conclusion of World War II fewer dollars would be available for research and development in a period of declining military preparedness budgets. The laboratory management also recognized that with the rapid disestablishment of the Nation's military machine and the accompanying trend toward disposal of equipment, material and supplies, large quantities of these items would be available and could be obtained and used to carry out research and development studies and test programs. It was further recognized that this could be accomplished largely without an expenditure of funds as the Government had previously effected payment and now held title to the needed equipment, materials and supplies. This approach made possible tremendous monetary savings and insured the availability of needed items during a period when many such items were not readily available on the commercial market. Butler Buildings, lathes, milling machines, grinders, safes, tables, desks, nuts, bolts, nails, and a thousand other items salvaged from the hurried abandonment of equipment and materials following World War II made possible the initial equipping and outfitting of the Defense Research Laboratory at a minimum cost.

Since 1945 the Defense Research Laboratory has played an important role in this Nation's research and development programs. From a single-

*Mach Number—The ratio of the velocity of a body to that of sound in the medium being considered.

†Nozzle—A duct of changing cross-section in which fluid velocity is increased. Nozzles are usually converging-diverging, but may be uniformly diverging or converging.

purpose beginning this Laboratory, by giving the military services more research and development information faster and at a lower cost, has become a center for research and development. Demands of the military for research and development work at the Defense Research Laboratory always exceed the available hours and personnel. The Defense Research Laboratory is located on 2.4 acres of land on the east side of the Main Campus and enjoys the proximity and full availability of the resources of The University of Texas. The work of the Laboratory is largely of a classified* nature carried out behind fenced security areas and is under a constant 24-hour-a-day security guard. The laboratory also, however, carries out some basic and unclassified research and development studies.

Each day some 200 persons flash identification badges before the vigilant eyes of the guard force to gain admittance to their work. Security is a part of their daily work and is conscientiously enforced. The staff consists of scientists, engineers, technicians, and administrative personnel comprising a group as varied as the work of DRL itself. Some are full-time employees, others top level university personnel teaching part-time and working at DRL part-time. Still others are graduate students working on advanced degrees. Close integration with the University's teaching departments makes available both teachers and students from the Department of Physics, Aeronautical Engineering, Engineering Mechanics, Chemistry, Mechanical Engineering, Drawing Mathematics, Psychology, Music, and others as dictated by specific problems. The working relationships between student and teacher in the laboratory foster understanding and friendship between the students and teachers. The benefits of the work to the students and teachers does not terminate here but manifests itself in many forms. The students holding positions on the DRL research staff while completing their degrees benefit greatly from the combination of academic and professional experience which they can offer to prospective employers. Graduates of the university who have gained this research experience while at DRL have been offered many outstanding positions in industry and other universities. As they move upward into more responsible positions after completing their formal education, new groups are brought into DRL in their place to back up the strong part-time and permanent full-time staff members. A small number are offered permanent full-time employment on the DRL staff.

Through this medium the Defense Research Laboratory enjoys a steady flow of young people including graduate students and younger staff personnel. This is one of the better means of keeping the laboratory strong over the years. History records that the power of a university to serve comes not from its facilities but from the steady flow of students. It is no less important to a laboratory to have a continuing supply of new talent and abilities. These graduate students and staff personnel are integrated into the work and operation of DRL. In this manner the Defense Research Laboratory produces not only good practical results but trains considerable numbers of young scientists who will do similar tasks in the future. By this method the Defense Research Laboratory assures in the same operation the results needed at the moment and the producing of scientific replacements by providing scientific and technical an-

*Classified matter is information or material in any form or of any nature which in the public interest must be safeguarded in the manner and to the extent required by its importance.

swers for the military while training and developing young men and women to enable them to better serve both civilian and military needs of this nation. Of course, since the work is classified these student employees are processed through the normal security checks.

The Defense Research Laboratory is operated on a non-profit basis. This laboratory carries out research and development for the military under contract on an actual cost basis with no fee. It is operated to assist the Department of Defense in the solution of problems for the security of this Nation and to provide a steady flow of competent and highly trained scientists and engineers to university, industrial and governmental pursuits. The work is carried out in buildings owned by The University of Texas supplemented by one Navy-owned building and Department of Defense-owned equipment.

This laboratory represents one of the finest facilities available to the Department of Defense in the Nation. Not only does it provide specialized research and development facilities, machine shops (Figure 7), chemistry laboratories and various other specialized equipment but also makes available by its close proximity and integration the talents, k n o w l e d g e and resources of the entire University of Texas.

The Defense Research Laboratory is one of the fruits of the vision of a relatively small band of realistic planners for this country's future protection. This group early in 1945, when victory for the allies was in sight, took positive steps to insure protection from foreign aggression by providing civilian activities to serve the military to assure that the scientific development of modern military weapons would never again be allowed to lapse as it had in the years prior to World War II.

Figure 7. Model and Machine Shop of the Defense Research Laboratory.

BOOK REVIEW

"PRACTICAL SHIPBUILDING"

by

Ir G. deRooij M.I.N.A.

Published in 1953

De Techniche Vitgeverij H. Stam—Harlaam Holland

387 pages, 812 figures, 58 tables

Reviewed by Owen H. Oakley

This book is the third in a series of seven volumes known as the "Ships and Marine Engines Series" being prepared under the general editorship of W. P. van Lammeran. It is the second of the series to be translated into English.

The field of practical ship construction has had few really complete treatises. Campbell Holmes classic of nearly fifty years ago has had no modern successor. This volume comes close to filling that gap. Holmes' book was primarily for the student while this one will probably prove more useful as a reference book.

The introductory section of Chapter I defines some basic shipbuilding terms and gives brief descriptions of the more important ship types. This part suffers from an attempt at being too elementary in treatment. This is followed by a discussion of the several classification societies and their characteristic numerals. The remainder of the chapter discusses riveting, welding, mechanical processes, and the properties of the more important materials used in shipbuilding. A wealth of basic information on these subjects is contained in this section; however, the standards for rivets, steel plates and shapes, etc. are European and do not correspond exactly with American standards.

The second chapter contains the real meat of the book. The various parts of the hull structure are rather thoroughly described and illustrated to show typical construction practices. The components are treated about in the same order in which they are handled in Lloyds and the ABS rules. Besides describing the configuration and arrangement of structural members, strength calculations of a type suited to drafting room use are presented for checking the more important of these members. Analyses of the strength of rudder stocks and of shaft brackets are given in considerable detail and several examples are worked out for these structures.

The final chapter consists of a more detailed description of the ship types covered in the introduction. Each type is illustrated by an arrangement profile and deck plan and a midship section. Typical dimensions and other data are tabulated.

The author is obviously a man of long and broad design experience, and the background material here presented make this a valuable book for any Naval Architectural library. The differences in standards and practices between European and American yards and materials invalidate some of the numerical data presented, as far as the American naval architect is concerned. Nevertheless the book is a valuable reference and is recommended reading for all those who are concerned with detailed ship structure design.

BOOK REVIEW

"THE DESIGN OF MERCHANT SHIPS"

by

J. C. AKEBROUT SCHOKKER

E. M. NEUERBURG

E. J. VOSSNACK

Published in 1953

De Techniche Vitgeverij H. Stam—Harlaam Holland

468 pages, 124 tables, 355 figures

Reviewed by OWEN H. OAKLEY

This book is volume four of a series of seven volumes known as the "Ships and Marine Engines Series," which is being published by the publishing firm De Techniche Vitgeverij H. Stam of Harlaam under the general editorship of W. P. van Lammeran. The series is being translated into English and this is the third volume to appear in this tongue.

"The Design of Merchant Ships" treats the design of merchant vessels under five chapter headings: I—Principal Dimensions Horsepower and Arrangement, II—Freeboard, III—Measurement, IV—Vibrations, and V—Strength.

For the most part the book is clearly written and the many figures are well executed. Both English and metric units are used, but in a way which does not cause confusion. This was done deliberately with the idea that a naval architect should be familiar with both systems. In covering each subject the authors have drawn heavily on the published literature and have documented their sources in comprehensive bibliographies at the end of each chapter.

Chapter I, by Schokker, on the basic design process, will be of particular interest to those who are engaged in preliminary ship design. Many empirical and fundamental relationships and extensive data on actual ships are given for determining the principal dimensions, estimating power, weight and so forth. Even though individual design methods may vary widely from those suggested here, this chapter contains a wealth of basic data which is most valuable in checking estimates made by other means.

Chapter II, on Freeboard, is thoroughly done. The background presented on the historical and technical development of freeboard regulations is most interesting. The freeboard regulations discussed are of course those contained in the Netherlands Shipping Order. Insofar as these reflect the dictates of the 1930 International Treaty the discussion applies to the U.S. freeboard regulations. However, naval architects in general will be concerned with the details of their own Government's regulations, and the thorough coverage of the Dutch regulations is therefore of secondary interest outside the Netherlands. This chapter and the following one on Measurement were written by Neuerburg.

The chapter on Measurement follows the same pattern as that on Freeboard. The historical review of tonnage measurement and the theories behind the rules make a most interesting study and are recommended reading for any naval

architect. Again the detailed coverage of the Netherlands rules will in general not be of specific interest to any but Dutch naval architects. The Suez and Panama rules are given brief but adequate coverage and are of more general interest.

It is unusual to find a chapter on hull vibration in a volume devoted to naval architectural design. Until now such information has been available only in scattered technical papers on the subject. This chapter discusses the several types of hull vibration, vertical, horizontal and torsional. The influences of such factors as wake distribution and multiple screws are described as also are methods of vibration measurement and neutralization. The greatest part of the chapter is given over to a rather complete coverage of methods of calculating natural hull frequencies. This chapter was written by Vossnack who unfortunately died shortly after completing it. This circumstance may account for the fact that this chaper appears to be somewhat less well edited than the others. The coverage, however, is good and the data furnished is valuable.

The final chapter, on strength, was written by Schokker. He uses the classical outline, discussing first longitudinal strength and then covering transverse, torsional, and finally local strength problems.

The discussion of longitudial strength includes a rather complete summary of the "Wolf" experiments and subsequent analyses thereof. Also included is a section on the behavior of light superstructures as treated by Muckle. Bruhn's method for handling transverse strength is described. Hovgaard's work on bulkheads and shell plating is included as is the application of Hardy Cross's method of moment distribution for analyzing redundant structures such as bulkhead and deck stiffeners.

The book is well worthwhile and is a real contribution to the literature of naval architecture.

BUYERS' GUIDE

Published by the British Gear Manufacturers' Association

Secretaries: Peat, Marwick, Mitchell & Co.,

301 Glossop Road, Sheffield 10, England

The 24 pages of this pamphlet are broken down into two sections, General Index and Range of Products. Under the former, the various British gear manufacturers are grouped under one or more of the following headings: Gears and Gear Cutting, Gear Units, Gear Cutting Tools, Gear Grinding, Gear Hardening, and Gear Prduction Machinery. In the Range of Products section, the manufacturers are listed alphabetically together with the type and size of products they manufacture.

THE RADIO AMATEUR'S HANDBOOK

32nd Edition 1955

Published by The American Relay League

West Hartford, Conn., U.S.A.

541 pages of text profusely illustrated plus 67 pages

of miscellaneous data.

Price: In the U.S.A. proper $3.00

In U.S. Possessions and Canada $3.50

Elsewhere $4.00

The 27 chapters of this handbook contain a revision of the previous edition. Among the principal revisions of the new edition are those in the vacuum tube tables and base diagrams. Two full pages listing 67 new tube types have been added to the miniature-tube section alone. Further additions include 26 crystal diodes, 19 rectifiers, 17 transistors and 32 other types. A complete listing of electrostatic cathode-ray tubes also forms a part of the tube tables.

The chapters concerned with very high frequencies have been extensively changed to improve clarity and to take advantage of techniques developed as a result of greater occupacy of this portion of the radio spectrum. Notable in this respect especially is the chapter dealing with v.h.f. transmitters, which includes equipment using tubes developed in the past year.

The high-frequency transmitter chapter also has been widely revised. Many new units are included, incorporating such features as continuous (multiband) tuning circuits and clamp-tube protective circuits.

As it has for a number of years, the handbook also contains a large catalog section, featuring equipment of the nation's leading manufacturers. In most cases, complete specifications and measurements are given for test equipment, antennas, keys, transmitters, receivers and other gear.

MAGNETIC AMPLIFIERS

By Dr. Herbert F. Storm

Published in 1955 by John Wiley & Sons, Inc., New York

and Chapman & Hall, Ltd., London

545 pages. $13.50

"Magnetic Amplifiers" is one of a series of books written by General Electric Company authors for the advancement of engineering knowledge. In this case some nine individuals, in addition to Dr. Storm, played major roles in its preparation.

The book might well be read with profit by practicing electrical engineers and

senior students of engineering. It presents the theory of single-phase, static magnetic amplifiers, together with theoretical and practical data on core materials, core-making techniques and metallic rectifiers. Throughout the authors approach their subject from a fundamental, physical point of view, avoiding, as they say, "mathematical complexity."

The book begins with 3 chapters on the modern theory of magnetism. Then follow 17 chapters on the theory of magnetic amplifiers, starting with the simple saturable reactors and progressing in logical order through higher forms of magnetic amplifiers to the self-excited or self-saturated magnetic amplifier (also known as the amplistat, Magamp or Magnestat).

Six chapters are devoted to applications of magnetic ampliers, starting with Dr. Alexanderson's applications to transoceanic telegraphy and telephony, and ending with the latest accomplishments in the field.

The authors have included a multitude of excellent illustrations and diagrams, together with abundant references to foreign and domestic sources.

THE GYROSCOPE APPLIED

By K. I. T. Richardson

Published, 1954, by

Philosophical Library, Inc., 15 East 40th Street,

New York 16, N.Y.

Printed in Great Britain

for The Philosophical Society

384 pages

In the Introduction, the author states, "The purpose of this book is to describe what the gyroscope is, how and why it works, and to indicate how and why it has come to play such an important part in scientific progress, especially in marine and aeronautical transportation and military operations."

The book is based upon "The Gyroscope and Its Applications," published in 1946, but which, because of security restrictions at that time, could not include much equipment developed in World War II. Many such items are included in the new book. The new materials and revisions were so extensive that the result is almost an entirely new book.

The author has divided the book into five sections, the first covering the fundamentals and basic principles. Then come sections on marine applications (gyro compasses, automatic steering control, and ship stabilization), aeronautical applications (navigational instruments, and automatic control), purely military applications (weapon sighting and missile control), and other applications (monorail cars and surveying instruments). Because the author is British, most of the applications are of British manufactured equipment.

Abundantly illustrated, the book is written to appeal to the non-mathematical reader. However, the appendix sets out mathematically the fundamental laws of the subject.

THE S. S. WARRIOR

An Analysis of an Export Transportation System from Shipper to Consignee

Publication 339 of the National Academy of Sciences—

National Research Council, November 30, 1954

54 pages, plus 18 enclosures, plus 21-page supplement

Price $1.00

This paper-covered book is the first of a series planned by the Maritime Cargo Transportation Conference of the National Academy of Sciences—National Research Council at the request of the Departments of Defense and Commerce.

The purpose of the overall program of which "The SS *Warrior*" is an initial study is to provide guidance on means and techniques leading to the improvement in the sea transportation of general cargo. The published study includes analyses of detailed information concerning the time, cost, and manpower involved in each step of the actual movement of cargo during an entire export transportation operation, from points of origin of the cargo within the United States through delivery at destinations in Germany.

In its conclusions, the staff of the Maritime Cargo Transportation Conference has identified and discussed those segments of transoceanic surface transportation that appear most capable of improvement, especially those segments in which a significant reduction in the turnaround time of general cargo vessels might be effected.

Ten tables summarize the facts regarding manhours, miles, costs and other aspects of each segment of the operation; and eighteen appendices graphically present analyses of the cargo involved, its origins and destinations, characteristics of the SS *Warrior*, cost-distance relationships, and cargo handling and stowage.

OBITUARY

The Society joins a host of others in mourning the death, in Miami Beach, Florida, on 6 April 1955 of

Rear Admiral Stanford C. Hooper, U.S. Navy, Retired

For thirty-five years Admiral Hooper was an active member of the Society and a contributor to the JOURNAL. Upon his retirement from the Navy he also retired from active membership in the Society but retained his interest in the JOURNAL as a reader.

The *Washington Post and Times Herald*, in its issue for 7 April 1955 described Admiral Hooper as "a pioneer in developing radio for the United States Navy" and covered his career with the following words:

> "Hooper was the first fleet wireless officer in the Navy, serving from 1911 to 1940. He was chairman of the radio division of the Navy from 1915 to 1927. A native of Colton, California, he graduated from Annapolis in 1905. He retired from active service in 1944 from a disability incurred in the war."

It might be closer to truth to say that Admiral Hooper was "the" rather than "a" pioneer in developing radio. He is widely known for his early *and* continuing work in this field.

Those who knew him in the Bureau of Steam Engineering when he was doing his pioneering remember him as a man of great personal courage. His professional courage can be attested by all who know the necessity for this qualification which is required in pushing the adoption of something new. The position reached in Naval Radio Communications, the first application of electronics, at the time of Admiral Hooper's retirement is a living testimonial of the magnitude of his contribution to his service and to his country.

The Society has been informed of the death of the following members since the publication of the February, 1955, JOURNAL:

CHURCH, ALBERT T., Rear Admiral, USN, Ret., Past Secretary-Treasurer

FORD, HANNIBAL CHOATE, Civil Member

CHANGES IN MEMBERSHIP

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6. Include on a separate page a short biographical sketch(es) of the author(s). 50 to 100 words for each author is desired.

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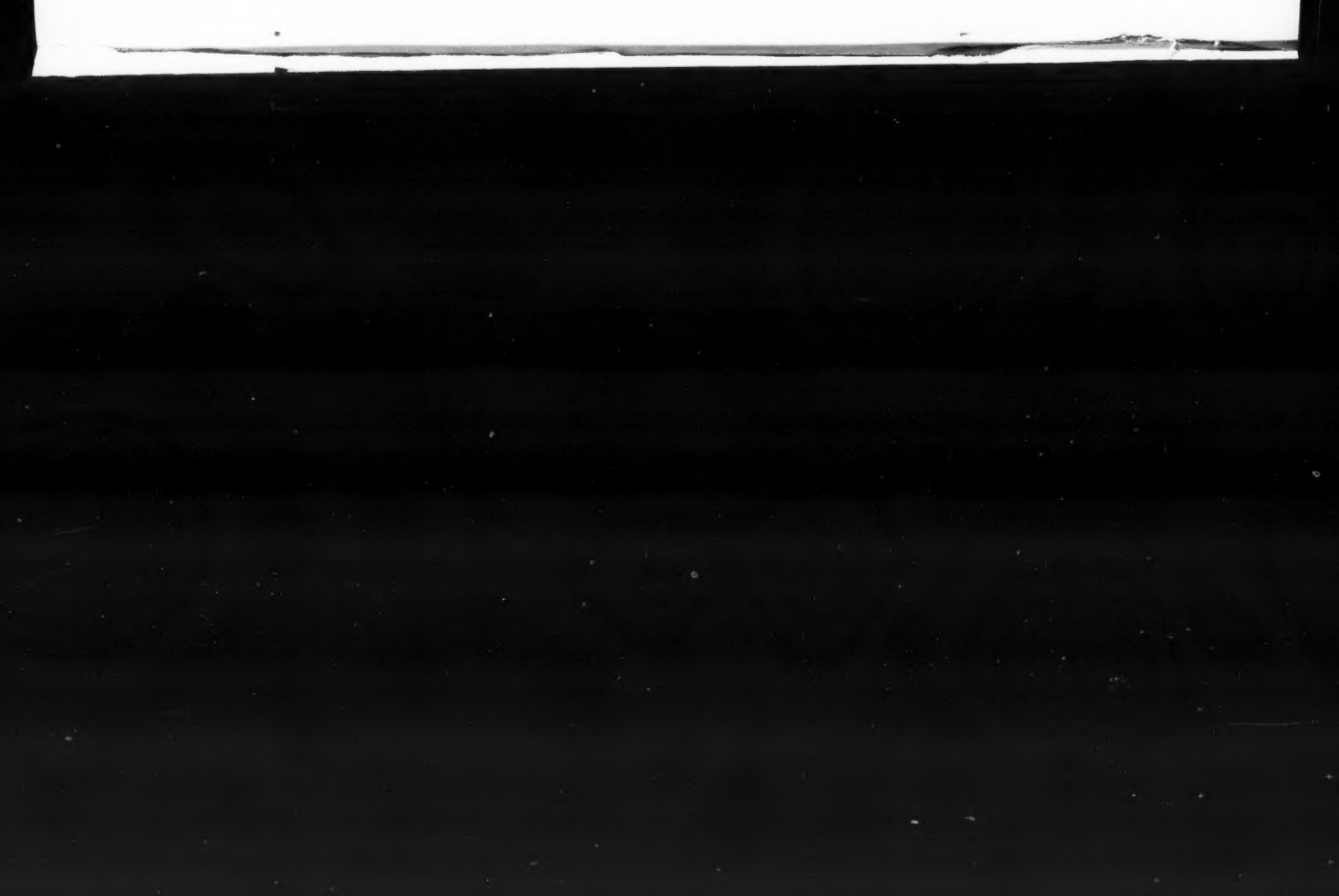

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